DIMENSIONS NBS

The magazine of the
National Bureau
of Standards
U.S. Department
of Commerce

May/June 1981

A NEW TWIST ON "DATING." See page 12.

COMMENT

MEETING THE CHALLENGES IN AUTOMATION RESEARCH

The article by John A. Simpson on automated manufacturing (see page 2) describes one of NBS' major programs in support of U.S. industry. The work is a direct descendant of NBS' measurement services for the metal-cutting industry. In earlier times the Bureau provided measurement services, particularly dimensional metrology, for a wide variety of specific shapes and sizes of metal products. About 10 years ago Simpson and his colleagues recognized that a more general approach was needed to avoid having to fulfill a near-infinite number of requests for calibration services. The new approach by NBS has produced a new era in mechanical metrology. Illustrating the change is the three-dimensional, coordinate measuring machine capable of defining automatically the shape and size of a wide range of objects. This machine is finding wide use in industry. Thanks to NBS efforts, errors in such machines may now be mapped and stored in the memory of computer controllers, and corrections are made automatically.

It is a logical step to move from the self-correcting, three-dimensional, coordinate measuring machine to a self-correcting machine tool. The self-correcting approach is being evaluated on milling machines in the NBS machine shop. A number of new challenges in measurement science in developing standard approaches to geometry, hardware and software interfaces arise as we contemplate tying together a series of automated machines.

Our goal is to provide the answers to these challenges such that U.S. industry's move to automated manufacturing is facilitated. U.S. industry has a great need for this technical assistance and we at NBS have launched a substantial program in response. Readers will find Simpson's review a fascinating glimpse into the measurement and standards business of tomorrow.

John W. Lyons, Director
National Engineering Laboratory
National Bureau of Standards
B119 Technology Building
Washington, DC 20234

DIMENSIONS NBS

The magazine of the
National Bureau of Standards
U.S. Department of Commerce
Volume 65/Number 4

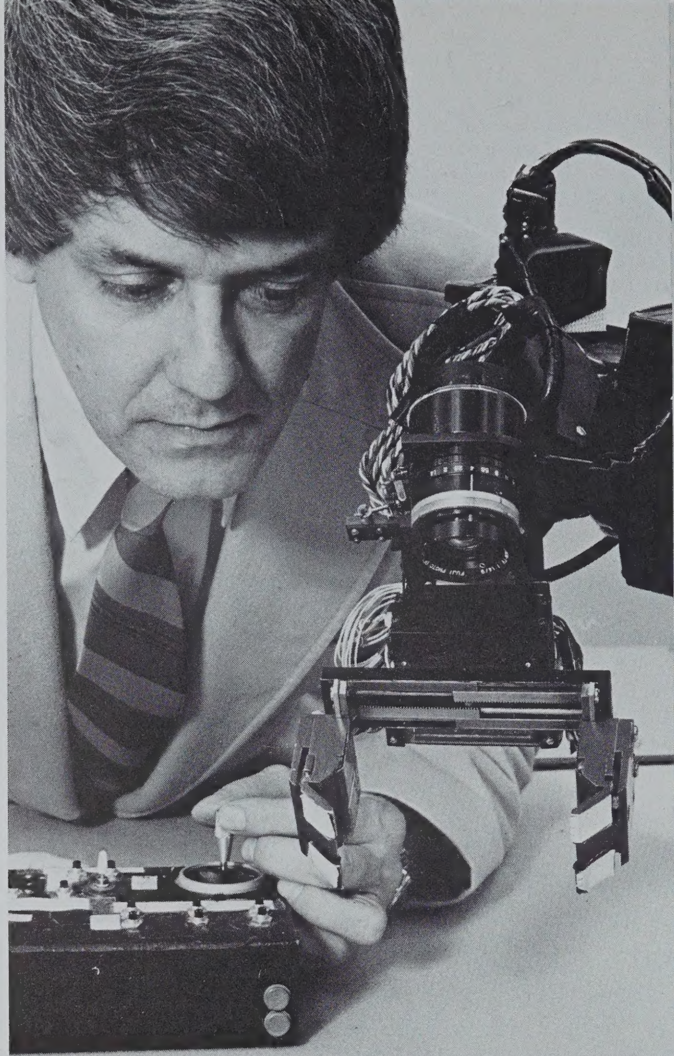
May/June 1981

Contents

ARTICLES

INTERFACE

UPDATE



James Albus, acting chief of the NBS Industrial Systems Division, with an experimental robot.

AUTOMATION

research at NBS

Seeking Generic Technology for the Automated Shop

by John A. Simpson

A major theme running through any discussion of American industry today is "productivity" and what can be done to increase it. The facts are:

- America's productivity is not increasing at the rate of that of other countries.
- Automated manufacturing and robotics have demonstrated productivity gains of 300 percent in selected industrial contexts where present technology is adequate.
- Present technology in the United States is not adequate to support automated manufacturing in the 100,000 small firms that make up over 80 percent of the discrete parts industry. This industry produces manufactured goods that account for 75 percent of the total U.S. trade.
- Japan and West Germany, two of our competitors for trade, have large and active national programs in automated manufacturing and robotics. These programs have, at the very least, brought their industry even with ours in this critical technology.
- Automation technology lacks standards, interfaces, measurement, and quality control. Areas that, because of their generic, industry-wide nature, and, hence, lack of market forces, develop slowly within the private sector.

These facts make it clear that well-directed research into the automation of discrete parts manufacturing can reap enormous benefits in productivity for American industry. The role of the National Bureau of Standards, as we see it, should be to tackle those generic problems that affect the entire industry, problems that require long-term research efforts related to our traditional strengths in metrology and standardization.

For the next 4 or 5 years we will be concentrating on setting up a completely automated shop, from design to manufactured product, using several computer-controlled work stations served by materials-handling robots. To accomplish this, we are looking at a few interesting problems in control and sensor technology.

Robots and the State Function

To be a practical tool in the sort of machine shop environment we are concerned with, an industrial robot will have to meet some fairly demanding criteria.

To begin with, the control system must interact in near real time with a sensory system capable of assessing the robot's environment and acting on this information in a goal-directed manner. That is, the machine must be able to respond to changes in its task and surroundings. It must be able, for example, to adjust if a part or tool is slightly out of position.

The control system should be as "friendly" as possible—programmed with a simple, English-like command language. This makes it easy to program the robot quickly, an important factor in whether or not the machine can be used for small batch runs.

The control should be as independent of specific data bases as possible to minimize the amount of reprogramming necessary to change jobs. Similarly, it should be easy to extend the programming language to new commands when necessary, since it is unlikely that all possible capabilities and sensors will be allowed for in the original language.

Finally, the control system should be, as much as possible, independent of any specific robot design—once again, to make it easy to expand and to adapt to new technology.

The approach we've chosen uses two parallel hierarchies. One is a control system in which each level accepts commands from a higher level, decomposes the commands to simpler subcommands, and sends these subcommands to the next lower level in the hierarchy. The other is a sensory feedback system which at each step in the hierarchy reduces the sensory input data to a form usable at the corresponding step in the control hierarchy.

Decisions are made at the lowest possible level in the hierarchy to shorten response time. At present we are working on a five-level hierarchy. The lowest level computes the functions for the individual servos in the robot; the second level transforms the coordinates describing the present and desired position of the robot into the coordinates of the robot joint; the third level receives simple task commands and translates them into motion commands; the fourth level receives complex move commands and breaks these down into simple task commands; and the highest level accepts commands from the programming language and breaks these down into elemental moves.

Each level in the hierarchy breaks time into a series of discrete intervals. For each interval the system receives commands, such as "move to a certain location" and sensory data on the robot's present location, and uses a comparatively simple algorithm to compute where the robot should move to in the next interval.

Simpson is director of the NBS Center for Manufacturing Engineering.

The big advantage to this system is that changes in the task can easily be accommodated at each level of the hierarchy. The system looks at the task anew at each interval and computes the motion of the robot only as far as the next interval. Since the intervals are fairly short—usually less than 20 milliseconds—the feedback data are essentially accepted and acted on in real time, and the system as a whole, of course, is goal-directed.

Going back to our criteria that an industrial robot must meet, we see that such a control system solves several problems. The highest level language can be made quite friendly, and changes to the system, such as adding high level commands at one end or extra sensor systems at the other end, need only be made at the appropriate level in the hierarchy. As a rule, only the lowest two levels are machine-specific, so the system as a whole is largely independent of the particular robot.

Another advantage of this hierarchical control scheme is that it allows us to use recent developments in powerful microprocessors that offer enormous increases in computing capacity at a very low cost. One of the most recent developments in our robot system was the implementation of the hierarchical control system on a series of individual microprocessors. Each level of the hierarchy has one or more microprocessors assigned to it.

Sensor Systems

The flexible, adaptive robot system we envision must have a very sophisticated sensory input system. In particular, if the machine is to locate parts and tools that are not precisely positioned, it must have a sense of the position and orientation of the part in space—that is, it has to be able to see.

We have such a vision system in place on our experimental robot now, and it is fairly well developed. The robot uses a light source mounted under its "wrist" to flash a plane of light parallel to its wrist axis. (The flash lamp is a modified photographic strobe light.)

The light plane illuminates any object in the robot's field of vision with a line of light across the object. The shape and orientation of the object produce easily identifiable changes in the apparent shape of the line. A cubical box seen edgewise produces a "v" shape, for instance, whereas a cylinder produces a more gentle curve. The box seen from a face produces a horizontal line. The shapes of the line is registered by a solid state camera mounted at a slight angle above the robot's wrist. The location of the apparent line of light in the camera's field of view, by triangulation, gives the distance to the object. (Reducing the object image to a simple set of line segments greatly reduces the computational problem. This improves the system's reaction time and, in addition, holds down the cost of the system —no small consideration.)

Our goal over the next 5 years is to adapt our experimental robot and vision system for use on the automated shop project. The robot and a horizontal NC (numerically controlled) machining center will comprise a work station in which the robot will load tools, fix workpiece clamping devices, load and unload parts to be machined, and perform part of the inspection procedure. This work station will be used to develop the command language structures, interface standards, control systems, and similar software and control design factors needed.

The Automated Shop

Machine tool metrology is, logically enough, one of our principal concerns in the one shop automation project. It bears directly on the issue of quality control, and improved quality control has been identified as one of the key factors in the planned renaissance of American industry.

Two fundamental measurement strategies can be used to monitor the quality of the product. The traditional approach in discrete parts manufacture is to measure the critical parameters of the product (either for each part or for some representative sample) at either the end of the production process or at key points along the way. At the very least, this allows you to reject flawed items; if the production process is sufficiently well known, it allows you to trace the errors to the offending production step and make appropriate corrections.

Now suppose that the production process is very well known. It is completely automated, so there is no human element, and the machines are deterministic in the sense that their behavior is completely known (within statistical limits, of course). In that case you have the option of measuring not the part in production, but rather the production process itself. If the process is "in control," the products will be good.

One of the chief elements in our shop automation research project at NBS is to push this concept as far as possible. What is needed are sufficiently "smart" sensors that feed data to a control system sufficiently smart to make corrections in real time.

In extending this concept, we're drawing heavily on a great deal of prior experience that we've had in the parametric calibration and computer correc-

Anthony Barbera, of the NBS Industrial Systems Division, at the programming console of an NBS experimental robot. Instrumentation on the robot includes a vision system and sonic sensors used as proximity detectors.

tion of our three-dimensional measurement facility used to calibrate coordinate measuring machines.

Our first test case is adapting a vertical spindle machining center. The research is partially sponsored by the Treasury Department's Bureau of Engraving and Printing, for which we are manufacturing a pair of high-speed rotary stamp perforating cylinders. These cylinders are an ideal test case. Their manufacture requires the drilling of 50,000 holes, roughly 1 mm in diameter, on the surface of a drum half a meter in diameter and about a meter in length. The hole centers must be located within 2 micrometers of nominal position over this 1 meter length.

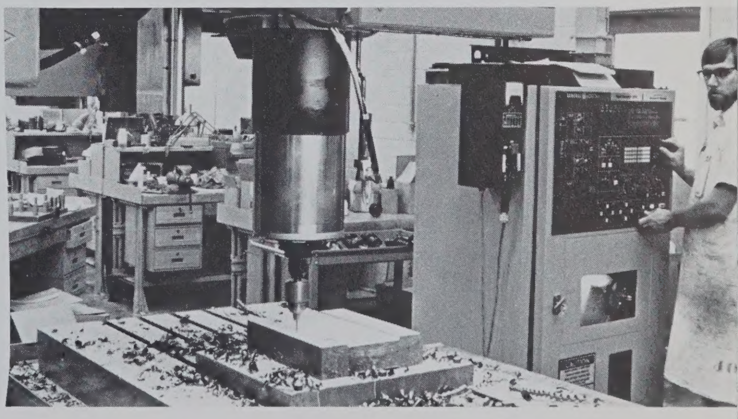
We plan to accomplish this by process controls rather than by in-built machine accuracy. Perhaps the easiest factor to deal with is static positioning errors. The machining center has three carriages moving in straight lines along three mutually orthogonal axes. Imperfections in the construction of the machine mean that each carriage has some built-in position errors, called "static" since they change only slowly with the wear of the machine.

We construct "maps" of these static errors for each degree of freedom by using laser interferometers. The data is stored in the memory of the computer control system. The control system then automatically compensates for the positioning errors by correcting the machine commands as they pass through the Machine Control Unit. This work is essentially complete for this machine.

Correcting dynamic errors, those which can be

Robert Hocken, acting chief of the NBS Automated Production Technology Division, shown at an experimental machining center station in the NBS shops. Sensors on the machine tool, and a pre-programmed set of "error maps" for systematic positioning errors, allow the machine's computer control to guide it with greatly improved accuracy.

Jeff Kelley, an instrument maker in the NBS Instrument Shops Division, tests the computerized numerically controlled machining center. The machining center currently is being used to manufacture a pair of high-speed rotary stamp perforating cylinders for the Treasury Department's Bureau of Engraving and Printing and to develop methods of improving machine tool accuracy.



expected to change while a part is being made, is somewhat trickier. Principal among these are errors caused by the thermal expansion of the machine base during operation. Although, in principle, one could correct for this by using a laser interferometer to plot error maps as a function of temperature or by using the same instrument to measure the thermal expansion and correct by real-time feedback, these approaches are somewhat impractical. The first is unattractive because of the storage requirements, and the second is both unreliable and costly.

A compromise is to instrument the machine with a number of thermistor temperature sensors linked to a computer that calculates machine distortions by final element analysis techniques. These distortions are then fed to the post-processor in the same manner as static errors. Once again, we are aided by the drop in computing costs brought on by large-scale integration of the electronic circuitry.

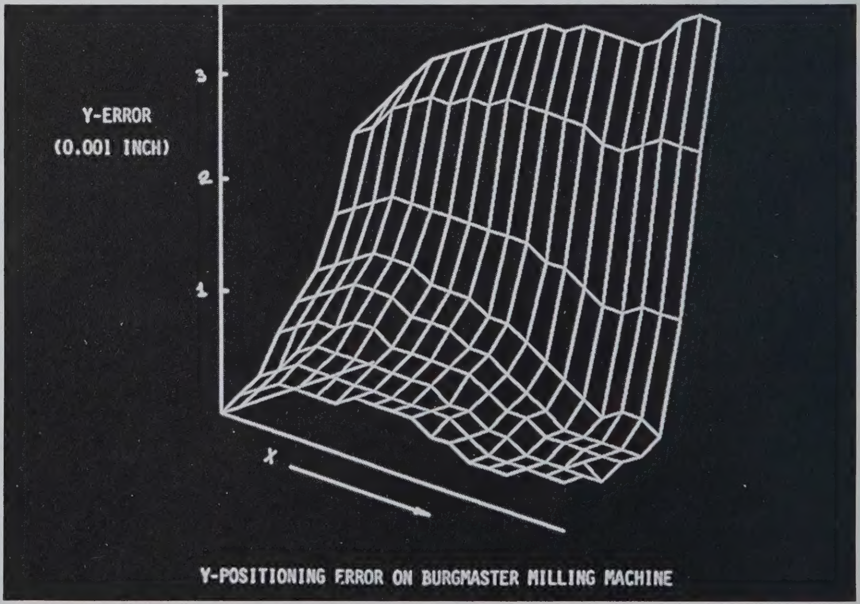
Other sources of dynamic error include tool wear, tool chatter, machine vibration, and spindle motion error (run out), the last of which is one of the most important. The practical solution to dynamic error seems to be a microprocessor-based system using some sort of position encoder, a high-speed sample-and-hold circuit, and an analog-to-digital converter. We have recently developed a displacement transducer to use in this system with wide bandwidth and several times the dynamic range of previous transducers. It can measure error motions at 512 points in angular resolution at speeds of up to 10,000 rpm.

Tool wear sensing is still in an early stage. Our preliminary tests indicate that some combination of acoustic emission signals generated by the drilling, power consumption measurements at the motor head, and measurements of the axial and radial forces transmitted by the work piece might be used to monitor tool wear.

To provide a test bed where we and our cooperating Industrial Research Associates and University Cooperatives can work on these problems, NBS is constructing a flexible manufacturing facility within its in-house machine shop. (Editor's note: NBS and industry are working together on four research programs aimed at specific improvements in automated manufacturing systems. See box.) This facility will consist of a series of manufacturing cells which when complete (in 4 or 5 years) will realize the technology necessary to automate fully the small job shop.

The specific, applied technology needed to boost America's productivity will be developed by the industrial community. The Bureau's automation technology program will provide a solid fundamental base on which to build. □

Error maps, programmed into a computer memory, record how the motion of a machine tool differs from the ideal as it travels along various paths. Computer controls can then automatically compensate for errors that are the result of mechanical flaws in the machine. Error paths are mapped with laser interferometers.



NBS, INDUSTRY WORK TO IMPROVE MANUFACTURING TECHNOLOGY

NBS and industry will be working together over the next few years on research programs aimed at specific improvements in automated manufacturing systems. Joining the NBS Center for Manufacturing Engineering in four of these projects are Deere & Company, Brown and Sharpe Manufacturing Company, Hewlett-Packard, and Lockheed Missiles and Space Company.

In a related program, the National Aeronautics and Space Administration (NASA) will be working with NBS on an assessment of the current state of robotics and artificial intelligence research.

Working With Coordinate Measuring Machines

Two projects deal with the accuracy of three-dimensional coordinate measuring machines used, for example, to check the precision of machined parts. Metrologists Susan Foss and Terry Gustafson from Deere & Company are on a 1-year project to develop a detailed measurement plan or algorithm for checking the machines, which are used extensively by Deere. The planned algorithm will check measuring machines for standard machine errors of scale, squareness, and the like, and for errors caused by other factors such as temporal drift, hysteresis, and operator variability.

In a related project, engineer Buzz Callahan from Brown and Sharpe is starting a 3-year project to study procedures for testing and calibrating coordinate measuring machines. This research, which is expected to be incorporated into a new American Society of Mechanical Engineers' standard for coordinate measuring machines, will include developing a complete geometric model of a coordinate measuring machine, noting the parameters that affect the accuracy and precision of the machine, creating "error maps" of these parameters to characterize the motion of the machine, and testing the error maps against transfer standards or laser interferometers.

Automating Measurement Systems

Automating a measurement system to increase productivity is one goal of the new research program set up by NBS and Hewlett-Packard. Working with a computer donated by Hewlett-Packard, NBS researchers are automating the laser interferometer system used by the Bureau to calibrate line-spacing measurements (measurements of the distance between the centers of lines). The new computer-controlled system will automatically collect and process data and should, at a minimum, quadruple the present productivity of the system. Working with Graham Siddall of Hewlett-Packard, NBS researchers will test the new system's ability to make reliable, long-term measurements on a relatively large number of line-spacing artifacts with accuracies approaching one-hundredth of a micrometer.

Increasing Machine "Intelligence"

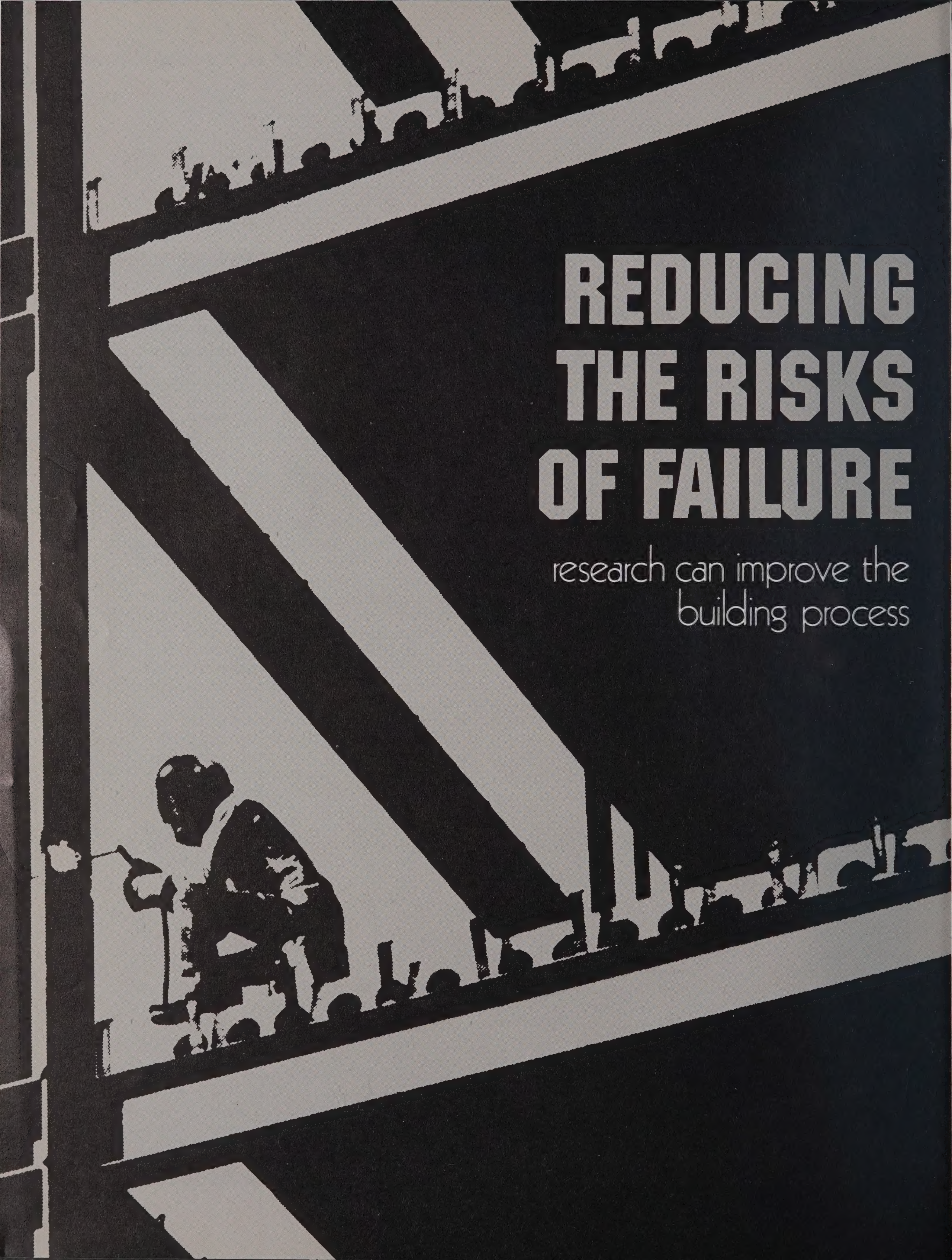
In a recently-completed project, engineer James Levins of Lockheed worked to develop an automatic tool-setting station for automated machining centers. In any plant using a large number of NC machines engaged in complex tasks, pre-setting these "tool compensation factors" requires a good deal of time, labor, and expense. Levin's project was to develop an automatic system that can be built into machining centers to allow each machine to pre-set its own tools.

Increasing the "intelligence" of machines is also a goal of a project in research planning being pursued by Bill Gevarter of NASA. The space agency is preparing a planning document on the current state of robotics and artificial intelligence research. The report, which will emphasize what robot devices are capable of doing now and in the foreseeable future, will be used by NASA in planning for future space exploration machines like the Voyager spacecrafts. Gevarter, a NASA policy analyst, will work closely with members of the NBS Industrial Systems Division, which includes one of the country's foremost research efforts in robotics. The report is expected to be complete within a year.

All of these cooperative projects are being conducted under the NBS Research Associate Program which allows skilled scientists and engineers from industrial, professional, trade, and similar organizations to work at NBS on specific projects under the sponsorship of their employers. The projects are chosen for mutual benefits to the sponsor and NBS, and both share in the results of the research. These results lie in the public domain and, thus, become available to all who might wish to take advantage of them.

REDUCING THE RISKS OF FAILURE

research can improve the building process



This text has been edited from a speech given by Richard D. Marshall, Group Leader of the Structural Engineering Group, at the Conference on Research for Building Construction Productivity on June 2, 1981. The conference was sponsored by the U.S. Chamber of Commerce and NBS.

THE building process today is faced with a dilemma. Because of inflation, dwindling productivity, and the demand for better building performance, innovation, new technologies, and a willingness to take the associated risks are needed to improve the building process. However, those involved in the building process often find the pressures of these challenges overwhelming. As a result, creativity is often suppressed and the status quo maintained.

To deal with this situation, three options are available to the building community. It can continue to accept the costs of liability insurance and current loss rates due to building failures, while looking to litigation for final resolution. However, building failures always involve a loss of resources, no matter how they are ultimately resolved or distributed.

It can adopt a more conservative (safer) approach to all phases of the building process. This will help diminish the likelihood of building failure, but safety and economy in design and construction must inevitably come into conflict.

Or, it can reduce the uncertainties in the building process through research and application of research findings and thereby reduce the risks of failure and, at the same time, increase productivity. Clearly the last choice is the most attractive over the long term.

Uncertainties Lead to Risk

Uncertainty, due either to design and construction variables or to human involvement in the building process, contributes to the risk of building failure. Design and construction uncertainties that could lead to failure include:

— Randomness of loads and no direct observations of extreme events.

— Loads due to unconsidered phenomena such as icing and accidents.

— Modeling errors.

— Randomness in material properties (including deterioration with time).

— Construction practice.

— Errors or breakdown in quality assurance and quality control procedures.

— Maintenance.

Design, production control, and compliance techniques and procedures can be used to reduce risks. With regard to structural *design*, current safety checking procedures are intended to account for the inherent randomness in loads and structural strength and, to some extent, errors in models used to predict load effects. Design quality control procedures are available for checking calculations and drawings. *Production control* includes insuring that construction materials are of acceptable quality and that errors during construction are limited. Typically, mill test data, and other materials certifications, and approvals of erection scheme and construction sequence are used. *Compliance,* as used here, means determining whether or not the completed structure complies with the engineering drawings and specifications. Conducting load tests, removing test specimens (roofing cuts or plugs), or exposure to environmental loads may be required.

Although these procedures and techniques are fairly well established they do not uniformly impact risks of failure. The designer in large part establishes or otherwise controls the overall chances of building failure through compliance with building codes and standards or through his or her own choice of design conservatism.

The designer usually seeks a balanced design in which initial costs are weighed against possible future losses. Although aesthetics and utility invariably come into play, the primary concern is with initial costs and expected failure losses. (Note that total cost is the sum of the initial cost and expected future losses. The expected future loss is the product of the cost of a failure and the probability that failure will occur.) The failure cost must be based on owner/user viewpoint and should include not only repair costs, but costs due to loss of inventory and loss of building use or service, and the cost of providing temporary facilities. For example, two identical warehouses with identical exposures to the elements would have the same chance of failing because of a windstorm, but the *costs* of failure would be drastically different if one were used to store digital computers and the other to store sand and gravel.

Beyond the design stage, the next important issue concerns the risk of building failure during construction. To promote competition and productivity, the contractor is usually given wide latitude regarding the construction sequence. However, in addition to stimulating innovative construction techniques, this approach also leads to innovative temporary structures that may be drastically different from anything

contemplated by the designer. In many cases the risk that the structure will fail while under construction is unacceptably high, even considering the short time span involved. For example, concrete masonry fire walls in light-frame construction are usually two and sometimes three stories high and often have very minimal wind bracing. In the interest of efficiency, they are constructed well ahead of the light-frame construction which ultimately provides lateral support. Wind force and moment coefficients for such walls are known, and it is highly probable that winds strong enough to cause failure will occur during the construction period. The frequency of reported failures tends to confirm these observations. The issue thus comes down to how the contractor can obtain and apply knowledge concerning the best way to erect the structure. Should the designer specify the construction sequence and carry out corresponding safety checks? Or should contractor-related organizations and associations develop guides to good practice that will reduce losses from failures during construction?

A third issue of considerable importance in any effort directed at reducing risk of failure is the concept of intervention. Regular maintenance is perhaps the most common form of intervention and can profoundly affect the probability of failure. Other forms of intervention that can be used are warning systems or changes in operating methods, such as shutting down and stowing large gantry cranes during strong winds. Both active and passive control systems have been proposed for the purpose of limiting building response to wind and seismic excitation. In certain cases natural damping has been augmented by the introduction of viscoelastic materials and tuned mass dampers. Improved, imaginative approaches to intervention hold great promise of reducing the risk of failure and thus lowering total cost.

Research Needs, Risks, and the Building Envelope

The problems relating to the building envelope, for which numerous failures have been reported in recent years, can illustrate how research and the application of research findings can reduce the uncertainties in the building process.

The building envelope, which in this context includes both wall cladding and roofing systems, can account for as much as 30 percent of the initial cost of a modern commercial building. Roofing systems alone amount to an annual market of some $4 billion. Savings to be realized through more effective use of materials, more efficient methods of fabrication and installation, and reduced risks of failure are therefore substantial.

Recent demands for increased fire safety and improved thermal performance have led to radical departures from past practices of fabricating and installing curtain walls and built-up roof membranes. This, combined with the fact that environmental loads and response characteristics of building envelopes are not fully known or understood, has led to abnormally high rates of failure.

In the case of built-up membrane roofing systems, the rate of premature failure has been put at 15 percent with some estimates ranging as high as 60 percent. One large liability underwriter reports that claims against architects for curtain wall failures have increased from 15 percent of all building failure claims in 1960 to 33 percent in 1980. While many failures of wall cladding have been reported, one of the more dramatic cases is the 60-story John Hancock Mutual Life Insurance Company headquarters building in Boston. After more than 3000 windows failed within the first year of service, all 10,344 windows were replaced with tempered glass at a direct cost of $6 million and an undetermined loss due to a 4-year delay in occupancy.

The major areas of research that can help reduce such failure losses include:

— Characterizing changes that occur in material properties over time.

— Characterizing loads.

— Identifying failure mechanisms.

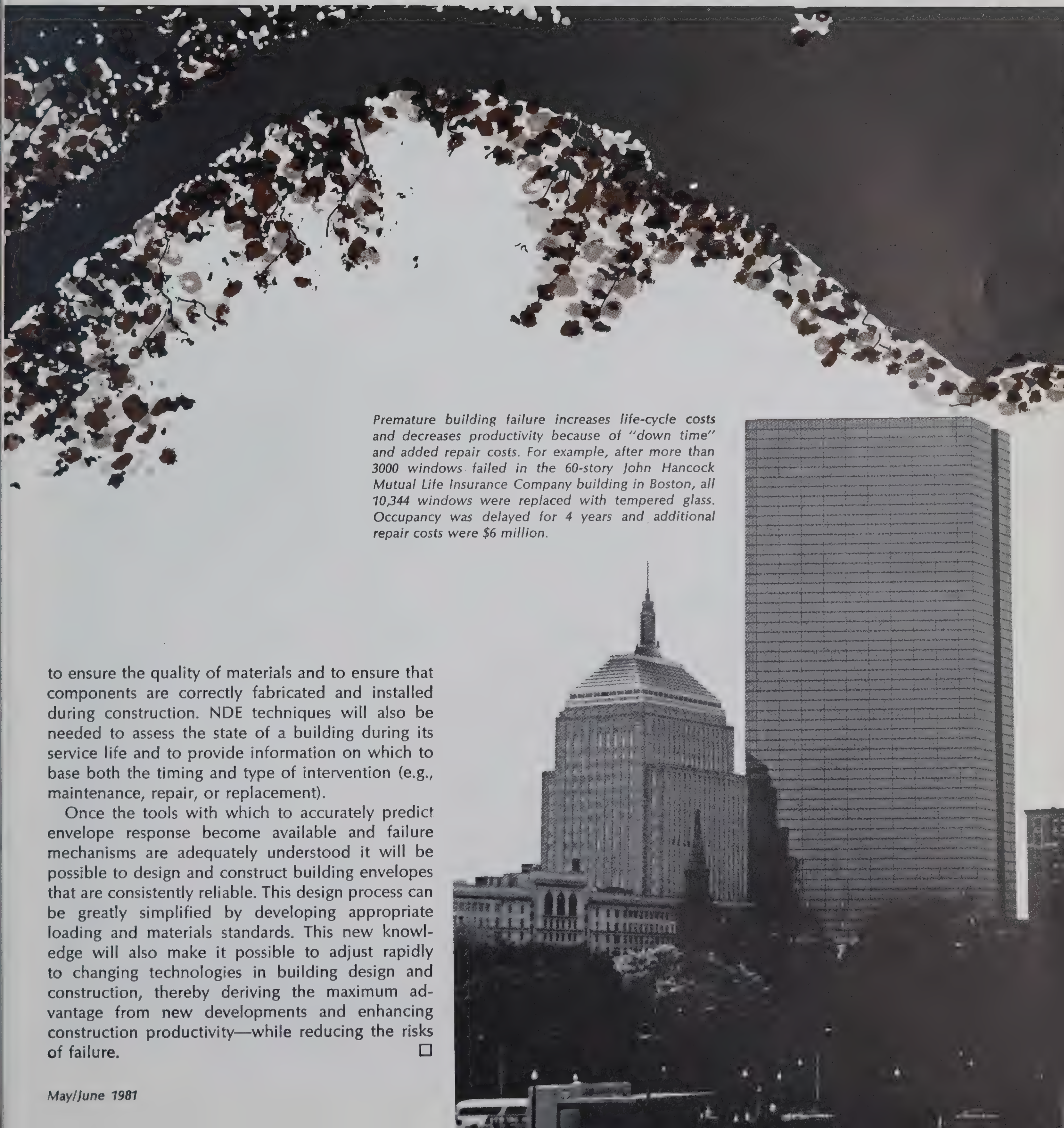
— Developing system response models.

— Developing nondestructive evaluation techniques.

— Optimizing intervention strategies.

With regard to the building envelope, characterizing the property changes that occur in materials over the years will require new measurement methods for assessing microstructural, physical, and mechanical changes in materials. Models for predicting the time dependent degradation processes in a given service environment will also need to be developed. Environmental loads, acting either singly or in combination, and their effects on the building envelope, must be described in terms of probability of occurrence. The same is true of system response models which must be applicable up to the point of failure. This will usually involve dynamic, nonlinear behavior.

Failure mechanisms and their probabilities of occurrence must be identified to establish effective serviceability and safety criteria. Finally, nondestructive evaluation (NDE) techniques will be necessary



Premature building failure increases life-cycle costs and decreases productivity because of "down time" and added repair costs. For example, after more than 3000 windows failed in the 60-story John Hancock Mutual Life Insurance Company building in Boston, all 10,344 windows were replaced with tempered glass. Occupancy was delayed for 4 years and additional repair costs were $6 million.

to ensure the quality of materials and to ensure that components are correctly fabricated and installed during construction. NDE techniques will also be needed to assess the state of a building during its service life and to provide information on which to base both the timing and type of intervention (e.g., maintenance, repair, or replacement).

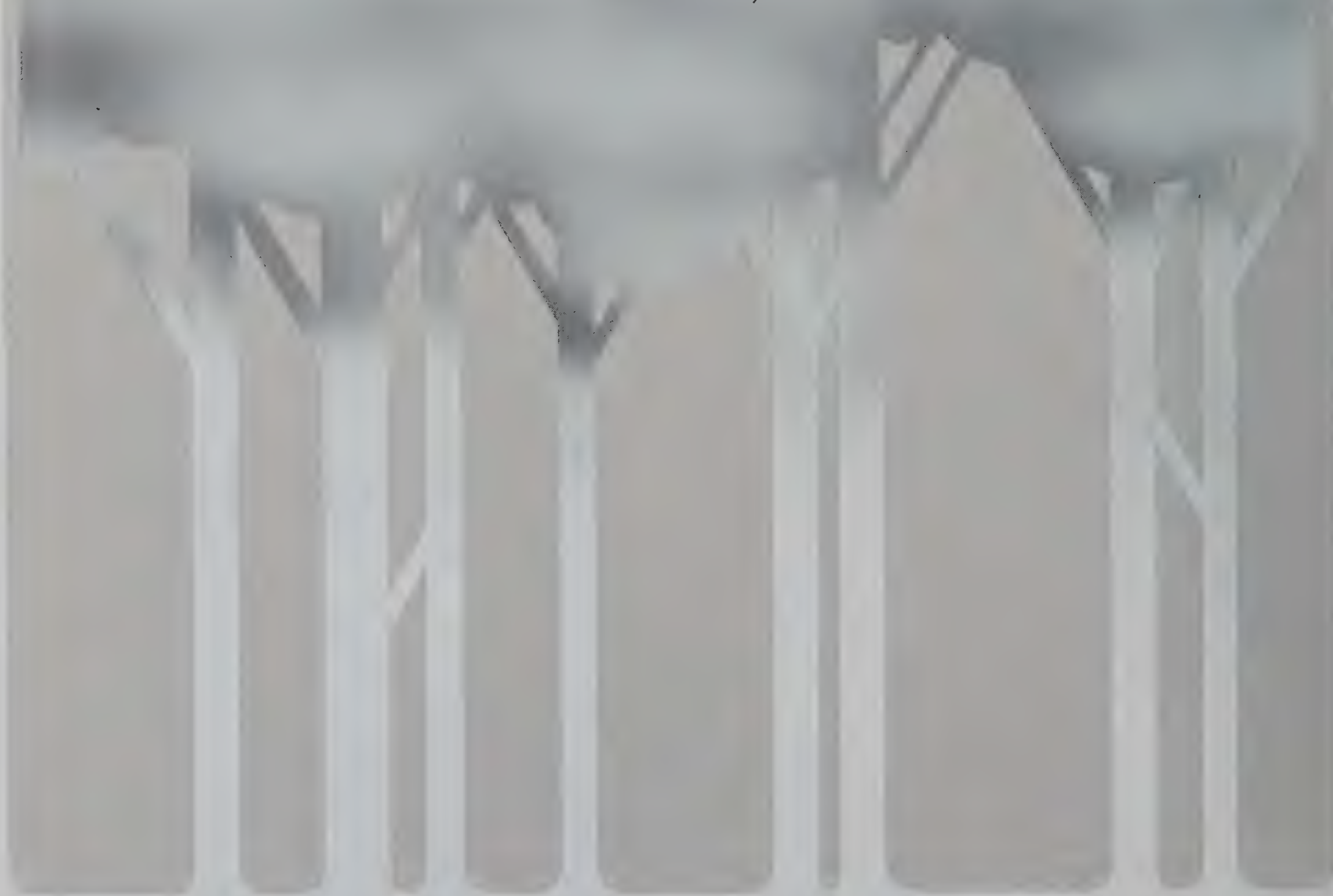
Once the tools with which to accurately predict envelope response become available and failure mechanisms are adequately understood it will be possible to design and construct building envelopes that are consistently reliable. This design process can be greatly simplified by developing appropriate loading and materials standards. This new knowledge will also make it possible to adjust rapidly to changing technologies in building design and construction, thereby deriving the maximum advantage from new developments and enhancing construction productivity—while reducing the risks of failure. □

COVER STORY

a new twist on "dating"

Radiocarbon Dating Techniques Applied to Air Pollution Studies

by Gail Porter



"The approach we've taken followed my reading in the journal, *Science,* about 6 years ago, that trees pollute. The authors suggested that a serious amount of urban pollution may come from nearby forests. What stirred in my mind at that point was that there is a superb way to get a direct answer to that question by measuring radiocarbon."

The speaker is Lloyd Currie, a research chemist at the National Bureau of Standards, and the subject is smog. Where does it come from? What is it made of? And how much, for example, of the Denver brown cloud is due to the burning of fossil fuels at factories or in cars, and how much is due to the breathing processes of trees or the burning of "natural" fuels like wood?

Inspired by the *Science* article, Currie and colleagues in the NBS Gas and Particulate Science Division have sought answers to these questions by applying radiocarbon dating techniques.

Radiocarbon dating, a method frequently used to establish the age of archeological artifacts or geological samples, involves measuring the ratio of unstable carbon-14 (C-14) to its stable isotope carbon-12 (C-12). During the late 1940's Willard Libby discovered that carbon-14 is produced in the atmosphere by cosmic rays and is distributed in the form of carbon dioxide throughout living matter by the respiration of plants. As long as a plant or animal remains alive it continues to exchange carbon-14 with the environment at a steady pace. After an organism dies, however, its level of carbon-14 is reduced gradually through radioactive decay.

After about 5700 years only half the original concentration of C-14 is left. This means that for artifacts younger than about 40,000 years old, scientists can calculate an approximate age by comparing the radiocarbon level found in the artifact with the level found in living matter.

It also means that measurements of radiocarbon can be used to discriminate between carbon compounds produced by the burning of fossil fuels and those produced by trees or by wood burning.

"Living" vs. "Dead" Carbon

"Fossil fuels such as coal and oil," says Currie, "are dead—that is, they lived some 300 million years ago, therefore the radiocarbon in them has long since decayed." In contrast, wood and organic compounds (eg. terpenes and isoprenes) which are emitted by trees, contain about the same level of C-14 as living matter.

An overbalance of atmospheric carbon produced by any of these sources can cause a number of problems. Particles of black elemental carbon (soot) are a major cause of pollution haze that reduces visibility. These particles also tend to absorb the sun's radiation, causing warming, and can reinforce the so-called "greenhouse effect" produced by excess carbon dioxide in the atmosphere. Some carbon compounds, such as certain forms of polycyclic aromatic hydrocarbons (PAH's), are known carcinogens or mutagens, while others can cause respiratory ailments. Certain organic carbon compounds can also cause formation in the lower atmosphere of ozone (which is toxic to humans and other animals). Paradoxically, still other organic compounds, like methane, can diffuse to the upper stratosphere and cause a breakdown of the beneficial ozone layer, which screens out harmful ultraviolet radiation from the sun.

"It's important," says Currie, "to know how much man contributes to the level of carbon in the atmosphere, because we don't have much control over nature. It doesn't make much sense to place strict controls on industry if their emissions are trivial compared to those from nature. On the other hand, we have plenty of evidence suggesting that industry's contributions are considerable. In order to help put environmental regulations on the soundest possible scientific base, we're trying to determine how much carbon comes from each."

While many scientists are analyzing the chemical and physical properties of pollutants in order to track down sources, Currie's research group is the only one he knows of using a radiocarbon technique to discriminate between fossil and biogenic pollution.

"The principle is beautifully simple," he says, "but very difficult to carry out in practice."

A first obstacle was to design a carbon-14 measurement system that could handle very small samples. In radiocarbon dating, Currie explains, a scientist generally uses 1 to 10 grams of carbon from an artifact to determine its age. But when even the most polluted urban areas seldom contain more than 50 micrograms (0.00005 gram) of carbon per cubic meter of air, "it would take several years to collect a 10 gram sample."

"We designed our system," he continues, "to deal with 1,000 times less sample or only 10 milli-

Porter is a writer and public information specialist in the NBS Public Information Division.

grams." In so doing, he adds, "We used all the techniques of conventional radiocarbon dating, plus a few extra electronic and chemical techniques to make the measurements feasible."

Vintage Iron

For instance, one of their first steps in constructing a small sample radiocarbon measurement device involved scavenging a World War I cannon barrel. By a stroke of good fortune, Currie managed to locate this gun barrel at the U.S. Naval Weapons Laboratory in Dahlgren, Va., just as it was scheduled to be recycled into new steel. Instead, Currie had a 1.7 meter (5.5 foot) section, weighing about 6 metric tons, cut out of the center of the barrel and shipped to the Bureau's chemistry building where it is now an integral part of his measurement apparatus.

Vintage iron, it turns out, provides an excellent radiation shield. When making precise measurements of C-14 it is important to protect the sample from extraneous natural background radiation coming from cosmic rays, building materials, or even from people. Unlike modern steel, the World War I barrel does not contain minute amounts of radioactivity from fallout or from industrial tracers that would interfere with carbon-14 measurements.

"People, by the way," mentions Currie, "contain about 1 million times as much radioactivity as we're trying to measure."

This brings up another problem. Because there is only about one carbon-14 atom for every trillion carbon-12 atoms in the atmosphere, a small absolute increase in the amount of carbon-14 produced can cause a large change in its relative concentration. Scientists believe that the concentration of C-14 has been close to equilibrium for much of the earth's history. That is, approximately the same number of C-14 atoms were being formed by cosmic rays as were disintegrating by radioactive decay, keeping the overall concentration stable.

Then from 1900 to about 1950, the huge amounts of "dead" fossil fuel carbon introduced into the atmosphere depressed the carbon-14 concentration

Research chemist George Klouda adjusts an electrical lead on a special gas proportional counter used to measure the ratio of carbon-14 to carbon-12 in air particulate samples.

by 2 to 3 percent from its "normal" level. After about 1950 a spate of atomic bomb testing overcompensated for this decrease by creating 100 percent more C-14 than would have been present naturally. (Free neutrons from nuclear explosions have the same effect in the atmosphere as neutrons from cosmic rays in producing C-14.) Since the mid 1960's the C-14 concentration has been gradually decreasing, approaching its historic level.

Vintage Wines

These variations made calculating an "average" contemporary concentration of radiocarbon difficult, says Currie, until a researcher in Portugal devised an ingenious solution to the problem. J. S. Lopes and coworkers in the Laboratory of Physics and Engineering in Scavém, Portugal, have measured the radiocarbon content of vintage Portugese wines dating from 1950 to the present. The result is an accurate record of radiocarbon concentration levels stretching back for several decades.

"We use this record," says Currie," as a calibration curve to correct our measurements."

The actual determination of the C-14 content of an air particulate sample begins when the researchers burn the sample completely to convert all of the elemental and organic carbon to carbon dioxide. The CO_2 is transferred to a gas proportional "counter" which consists of a high purity quartz cylinder lined with copper foil and containing a central tungsten wire. The counter is then enclosed in a shield of high-purity copper about 13 centimeters thick, inserted into the center of the gun barrel, and protected against outside interferences with two heavy steel doors.

Now the counting can begin. A negative potential is applied to the foil lining, leaving the central tungsten wire with a relative positive potential. Each time a C-14 atom decays, says George Klouda, a research chemist working with Currie, an electron is ejected from the atom's nucleus and is accelerated toward the positively charged wire. This produces an electrical pulse which is recorded and stored by a minicomputer.

With the help of a mathematical chemist, Robert Gerlach, Currie and Klouda analyze the data generated by the computer, making sure that each signal has an energy level and "pulse shape" matching those of radiocarbon and was not caused instead by random electrical breakdown or by residual radioactive impurities in the counter or shielding materials.

The design of their counting system also eliminates the possibility that signals produced by mu-mesons will be mistaken for decaying C-14. Mu-mesons are high energy particles produced by cosmic rays, and they will penetrate, says Currie, "many meters of earth or many shields." To avoid having to go underground, the NBS researchers enclosed the sample with its copper shield in a second gas portional counter. This counter is analogous to the primary system except that it contains many tungsten wires rather that just one. (See diagram.) The electronics of the NBS system are designed to cancel any signals detected simultaneously within both the outer and inner counters. Simultaneous signals indicate a particle has penetrated through the entire apparatus and consequently could not have been produced by radiocarbon within the sample chamber.

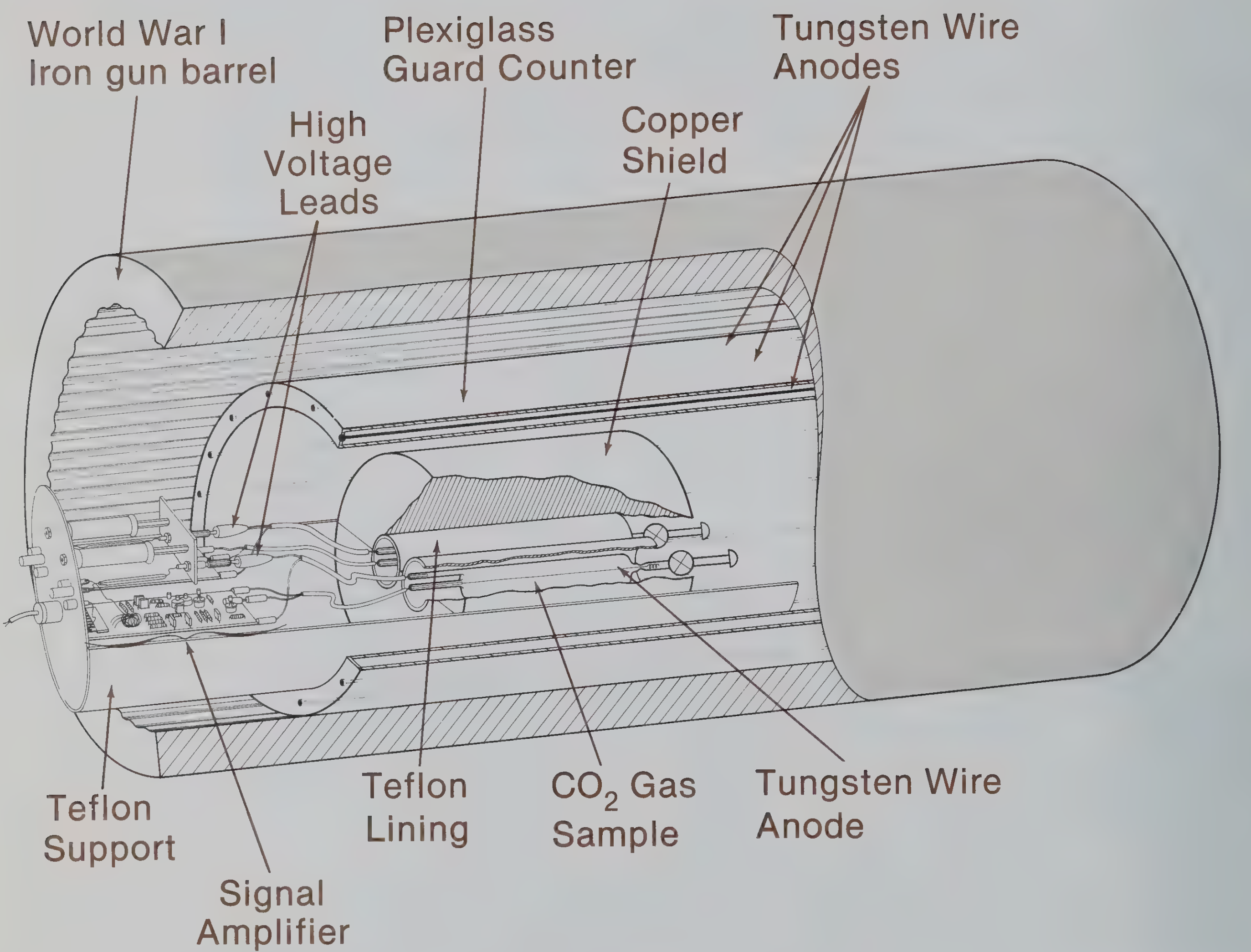
From Cities to Forests

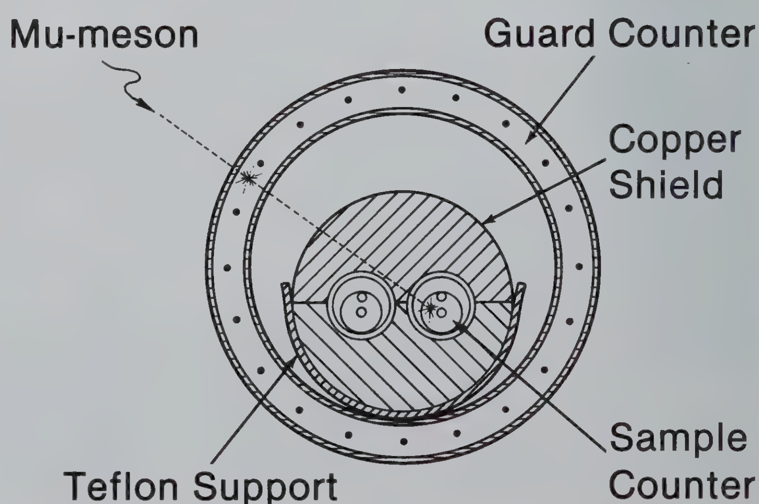
Of course, the most interesting part of their experiments are the results. "We've been cooperating with a number of universities, other government agencies, and corporations," says Currie, "in the analysis and sampling of particulates from different types of areas." So far, they have received particulate samples collected in a number of U.S. cities, in the Utah desert, in a remote forest in Russia, in the Virginia Shenandoah Valley, and in places with apparently unique pollution problems like Barrow, Alaska.

At tiny Barrow, residents are subjected each spring to pollution comparable to that of major metropolitan areas. There has been some speculation, says Currie, that the Point Barrow haze is coming over the North Pole from Russia or Europe. "It will be very interesting to find the radiocarbon concentration of these samples," he says.

In other places, says Currie, they have found that the percentage of biogenic carbon in particulate samples varies considerably depending on the time of the year and other factors. "We've found the full range of concentrations from nearly all biogenic to nearly all fossil in a number of our studies."

In a project carried out in December 1978 in Denver, Colo., with General Motors, the researchers found that the percentage of "living" carbon in air particles varied from as low as 10 percent to as much as 55 percent depending on factors such as the time of day, the day of the week, and the outside temperatures. A large percentage of living





These cross-sectional and horizontal cutaway diagrams of the NBS carbon-14 counter show how the sample is shielded from background radiation, which would interfere with the measurements. Even mu-mesons are canceled out by an extra guard counter. Signals detected simultaneously by both the outer guard counter and the inner sample counter indicate a particle has penetrated through the entire apparatus and could not have been produced by radiocarbon within the sample.

carbon, for example, was recorded on a day when there was known to be a high degree of residential wood burning.

Another study, done in cooperation with the Oregon Graduate Center in Portland, Oreg., found that on days when local lumber and grass-seed companies carried out a process called slash and field burning, nearly 100 percent of the carbon in the haze over downtown Portland came from "living" carbon sources.

In a suburb of Los Angeles, the weather was the determining factor. A study with the University of California showed that the concentration range depended most strongly on which way the wind was blowing, from the traffic-congested center of the city or from the neighboring forests.

Having to deal with so many complex variables in determining pollution sources, says Currie, makes the Environmental Protection Agency's (EPA) job a lot harder. So EPA is helping to fund a number of research projects, including Currie's, to try to get as much chemical and physical information as possible about air particulate samples. The more detailed these analyses become, the more likely it is that sources of specific portions of the particulates can be traced accurately.

Future Directions

A new analytical technique that could help this process along considerably, according to Currie, is called accelerator mass spectrometry. This technique has been developing over the last 2 or 3 years and "promises to be very exciting indeed for pollution studies, geochemistry, and a wide range of other chemical composition studies," says Currie.

The method involves accelerating atoms to extremely high energy (mega electron volts) using the techniques of nuclear physics. The advantage of accelerator mass spectrometry is that atoms such as C-12 and C-14 can be very accurately distinguished not only by mass but also by differences in energy loss as the atoms pass through a detector. As a result, accelerator mass spectrometry, says Currie, improves the sensitivity of radiocarbon measurements by a factor of 1000. It can measure isotope ratios such as C-14 to C-12 down to one part per trillion and below, "far beyond what conventional mass spectrometry can do."

In recent tests performed using an accelerator at the University of Rochester, Currie and his coworkers were able to measure the radiocarbon concentration of a 40-microgram carbon sample in only 15 minutes. With their current system, it would take a day or more to measure samples 100 to 1000 times larger.

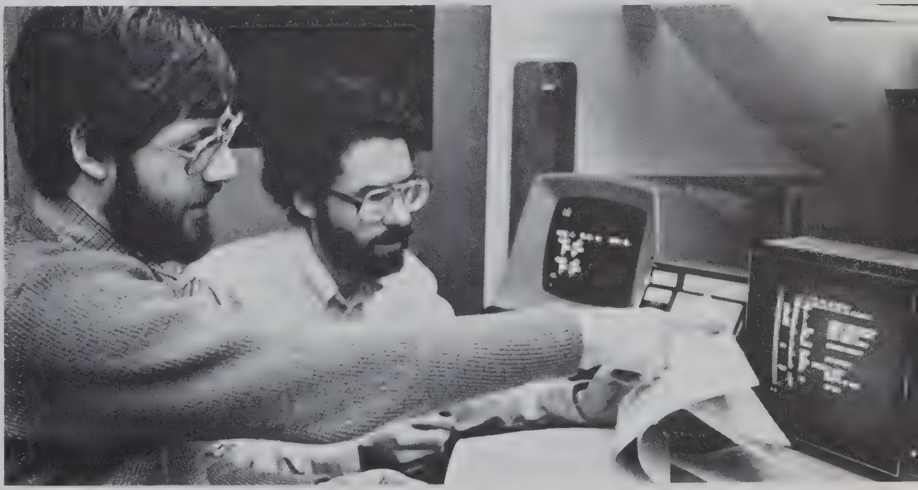
Consequently, says Currie, "we chemists are flocking to these laboratories to use their facilities."

This doesn't mean they will be forsaking their unique gun-barrel counter, however. In the future, says Currie, they will be focusing on improving the accuracy of their measurements by methods such as isotope enrichment, where the heavier C-14 atoms are partially separated from the C-12 atoms with a technique called thermal diffusion. The resulting sample has a higher concentration of C-14, and it is then easier to measure accurately.

They will also be using "wet chemistry" to separate different carbon fractions and determine sources of origin. According to Currie, they have already used chemical separation successfully to establish that PAH's found in sediments of the Puget Sound in Washington contain little or no radiocarbon. This suggests that these compounds result from fossil fuel use rather than from natural forest fires or other biogenic sources.

The field of radiocarbon chemistry, says Currie, "has an exciting future. Advanced measurement techniques make it possible for the first time to detect radiocarbon in individual chemical fractions of very small samples. This, together with high-resolution sampling, will greatly increase our understanding of the flow of carbon throughout the environment." □

Klouda and mathematical chemist Robert Gerlach review data generated by the computer to be sure that each signal has the "pulse shape" and energy characteristics of carbon-14 and was not caused by random electrical breakdown or by residual radioactive impurities in the counter or shielding materials.



ON LINE WITH INDUSTRY

RESULTS OF "SOFT ALUMINUM" STUDY ANNOUNCED

Scientists at NBS have just published the results of a comprehensive study of the so-called "soft aluminum" problem. Their findings could have important implications for metal manufacturers in improving nondestructive evaluation methods to ensure reliable processing of aluminum alloy plates.

The study was initiated shortly after the announcement in August 1979 by the Reynolds Metal Company that about 31 million pounds of aluminum were suspected of containing "soft" spots due to a possible malfunction in the water cooling system at one manufacturing plant. Some of these "soft" spots were reported to be as much as 45 percent below the strength specifications for the purchase of the aluminum by aircraft manufacturers and suppliers.

There was also concern, according to William McInnis of the National Aeronautics and Space Administration (NASA), that defective aluminum may have been used by NASA contractors in building the space shuttle's external fuel tank, a structure that carries liquid hydrogen and oxygen under high pressure and that must withstand the stress of launching.

Following a comprehensive 13-month investigation for NASA of the specific alloy used in constructing the fuel tank (2219 aluminum alloy), NBS researchers concluded in a 235-page report that even under "worst case" manufacturing conditions at the Reynolds plant, aluminum plates measuring approximately 5 cm (2 inches) thick and less would still meet Federal strength specifications. (This worst case assumed the proper operation of the water cooling system on just one side of the plates.)

The result is valuable, said Robert Mehrabian, chief of the NBS Metallurgy Division, because much of the material used by NASA falls within this projected safe thickness range. For several reasons, including a relatively high copper content, 2219 aluminum alloy is probably much less sensitive to the type of improper cooling that may have occurred at the Reynolds plant than are other aluminum alloys, he added.

The NBS project was basically an engineering study that helped nail down the values of various processing parameters needed to produce 2219 aluminum alloy that meets certain specifications. While the identities of many of these parameters were largely known before the study, the data collected can be used to cite specifically what kind of microstructure and properties can be expected from a particular set of processing treatments.

For example, a computer program was developed that correlates variations in processing time and temperature directly with changes in precipitation (formation of particles rich in copper), and consequently with differences in hardness, yield strength, tensile strength, and electrical conductivity.

Bureau researchers also concluded that eddy current testing may not provide as dependable a measure of alloy strength as has been previously thought. Eddy current testing is basically a surface (or near-surface) measurement technique that involves measuring changes in the electrical conductivity of a metal to judge its strength or to detect flaws. However, processing variables such as ingot scalping and thermomechanical treatments (including quenching or aging times and temperatures) can affect eddy current testing in ways unrelated to the alloy's overall properties.

For example, a comparison of yield strength measurements to eddy current measurements made for NBS by four laboratories showed wide variation. This variation was attributed to the sensitivity of eddy current testing to small differences in processing rather than to the measurements themselves. Hardness measurements were less sensitive to processing variables, and so the report suggests hardness tests be used to corroborate eddy current results.

An improvement of both these methods would be an ultrasound technique capable of judging alloy strength. Although ultrasound is widely used to find flaws in alloy plates and welds, the complexities of the method have prevented its application to strength measurements. Now that NBS researchers have a well characterized alloy to work with, they are collaborating with a guest worker from the Johns Hopkins University to develop an ultrasound method for making indirect strength measurements throughout the thickness of an alloy plate. Such measurements would be based on differences in the attenuation and velocity of high frequency sound waves when they are passed through alloys with different microstructures.

At NASA's request, NBS researchers currently are studying another aluminum alloy, 2024, that is more widely used in the construction of commercial aircraft. Funding for both this and the previous study has been coordinated through the NBS Office of Nondestructive Evaluation.

A copy of the Bureau's completed work, *NBS: Nondestructive Evaluation of Nonuniformities in 2219 Aluminum Alloy Plate—Relationship to Processing* (NBSIR 80-2069), is available from the National Technical Information Service, Springfield, VA 22161, for $18.50 prepaid. Order by PB 81-172348. G.P.

CORRECTION It has come to our attention that on page 18 of the December 1980 issue, an article on the Bureau's use of neutron radiography to inspect a compact jet engine's oil levels omitted mention of related research in Great Britain. The article said that the NBS work "illustrates the usefulness of neutron radiography as a promising new research tool" for engine designers. Led by P.A.E. Stewart, scientists from Rolls-Royce and the U.K. Atomic Energy Research Establishment had earlier conducted similar research. The British researchers used lower energy neutrons with a real-time imaging system on a gas turbine engine. We regret the omission.

INDUSTRY GAS SUPPLIERS TO PRODUCE CRM'S

In an effort to ease the current shortage of high accuracy standard gas samples used in calibrating pollution measurement instruments and methods, the National Bureau of Standards and the Environmental Protection Agency (EPA) have developed a procedure to allow commercial gas suppliers to produce certified reference materials (CRM's) that are traceable to NBS Standard Reference Materials (SRM's).

The procedure, to be published as a joint NBS/EPA report, provides for the production by specialty gas companies of standard gas mixtures (such as carbon monoxide in air) according to protocols specified by NBS and in accordance with a quality control program audited by EPA.

The use of CRM's will be accepted by EPA as meeting ambient air and stationary source emissions regulations that require gas standards to be "traceable to NBS Standard Reference Materials." In the future, CRM's may also be used for emissions testing associated with mobile sources.

NBS began producing gaseous SRM's more than 12 years ago, at a time when no universally acceptable reference materials were available for gas measurement. The production of these reference materials has helped to prevent discrepancies between measurements made by EPA and those made by vehicle manufacturers, power utilities, chemical producers, and other companies that must comply with EPA pollution control regulations. An SRM certified to contain a known concentration of a given pollutant provides their monitoring of instruments and methods.

"Since the start of the NBS gas SRM program," says NBS research chemist Ernest Hughes, "the accurary of gas pollutant emissions measurements has improved considerably." Also, in the process of producing these SRM's, he says, NBS researchers have developed measurement and production methods that greatly improve the accuracy and stability of the standards themselves.

However, the stringent quality control required for the Bureau's SRM's makes production of large volumes of the reference materials unfeasible. Typically, about 50 cylinders containing gas mixtures of a given class can be certified as SRM's in one batch. Because of the large number of reference materials needed by industry to ensure compliance with environmental regulations and a low production capacity at NBS, the demand for gaseous SRM's has outstripped supply. Currently it may take 6 months to 1 year for a customer to receive a gaseous SRM.

The new NBS/EPA procedure, says Hughes, should allow scientists and engineers to buy industry-produced CRM's with confidence that certified concentration levels are accurate and traceable to the National Bureau of Standards. In addition, gas manufacturers should be able to produce CRM's in larger sample volumes and at lower cost than NBS can make equivalent SRM's.

Each batch of CRM's must be compared by the gas producer to SRM's of the same concentration level, immediately after preparation and again after at least 1 month to ensure stability. The measured concentration level for the CRM's must agree to within 1 percent with the concentration specified on an SRM certificate. (CRM's cannot be prepared in concentrations where there are no SRM's available for exact comparisons.)

Samples from each batch of CRM's will also be compared to corresponding SRM's by an independent laboratory under contract to EPA. All of the measurement data and a description of the analytical procedures followed by both the EPA auditor and gas producers will be examined by NBS. If the two analyses disagree, NBS will acquire additional information as needed to resolve the discrepancy.

The first CRM's to be produced by industry suppliers will be mixtures of carbon monoxide in nitrogen and carbon monoxide in air at molar concentrations ranging from 10 parts per million to 8 percent. Once the new procedure proves successful by the production of these reference materials at acceptable levels of accuracy, CRM's for oxides of nitrogen and oxides of sulfur will be added to the program.

For additional information, or to obtain a copy of the NBS/EPA report, *"A Procedure for Establishing the Traceability of Gas Mixtures to Certain National Bureau of Standards Standard Reference Materials* (EPA No. 600 47-81-010), contact the Office of Environmental Measurements, A261 Metrology Building, NBS, Washington, DC 20234, Phone 301/921-3775.

G.P.

NEW STANDARD RADIATION SOURCE POSSIBLE

NBS scientists, in collaboration with the University of Maryland and the University of Dublin, have measured the characteristics of a new source of continuum radiation in the vacuum ultraviolet wavelength region shorter than 220 nm. These measurements indicate that this source could possibly serve as the long-sought portable intensity standard spanning the spectral region from soft x-rays to the near ultraviolet.

James R. Roberts, William R. Ott, Mervin Bridges, and Tim Pittman, Atomic and Plasma Radiation Physics Division, A167 Physics Building, 301/921-2356.

Radiation sources that are free of spectral lines and have a strong continuum are attractive as possible radiant intensity or irradiance standards, since calibrations can be done at any wavelength and for any spectral bandpass. Except for the NBS argon mini-arc and the commercially available deuterium lamp, there are no portable radiometric standards for the vacuum ultraviolet. For wavelengths shorter than 115 nm, where the lamp windows cut off, there are no transfer standards at all.

The new pulsed source, requiring no window, is a vacuum source and emits a line-free continuum from 4 nm to 220 nm. The source is a laser-produced plasma generated when a Q-switched ruby laser with nominal energy requirements (1-3 joules, 30 ns pulse width) is focused on the surface of a rare earth target, e.g., ytterbium. The radiation pulse was found to be a weak function of the delivered laser pulse, which was monitored, on a shot-to-shot basis. At laser energies larger than 0.5 joule, the output of the plasma is relatively insensitive to changes in the laser energy as if the output radiation were approaching a maximum. Some scientists believe that this effect is due to absorption of the laser beam at very high densities. The absorption limits the amount of laser energy available to heat up the core of the plasma and leads to a kind of saturation phenomenon.

The new source was calibrated for spectral irradiance (W cm^{-2} nm^{-1}) by comparison with a recently NBS-developed argon mini-arc irradiance standard in the wavelength region 115 to 220 nm. The spectral irradiance of the pulsed plasma source was about 100,000 times greater than that of the mini-arc at 180 nm and even greater at shorter wavelengths. From photographic spectra taken, the peak of the spectrum appears to occur at extremely short wavelengths in the 5 to 25 nm region.

This new source could be applied in many technological areas requiring ultraviolet radiation sources that are reproducible and have high intensity, smooth continuum, and extensive wavelength coverage. What is perhaps even more significant is that it could serve as an *"in situ"* ultraviolet intensity standard for many types of plasma physics experiments. For example, laser scattering is one of the most common diagnostic methods used on fusion machines to determine electron temperature and density. This means that the ruby laser system and optical equipment needed to produce the "standard" plasma is already in place in most laboratories. To calibrate the sensitivity of vacuum ultraviolet radiation instruments, one needs only to introduce a suitable target at the focus of the laser beam. The radiation from fusion plasma devices (e.g., tokamaks) or other types of plasmas can then be compared to the standard plasma, related to an absolute scale, and used for additional diagnostics.

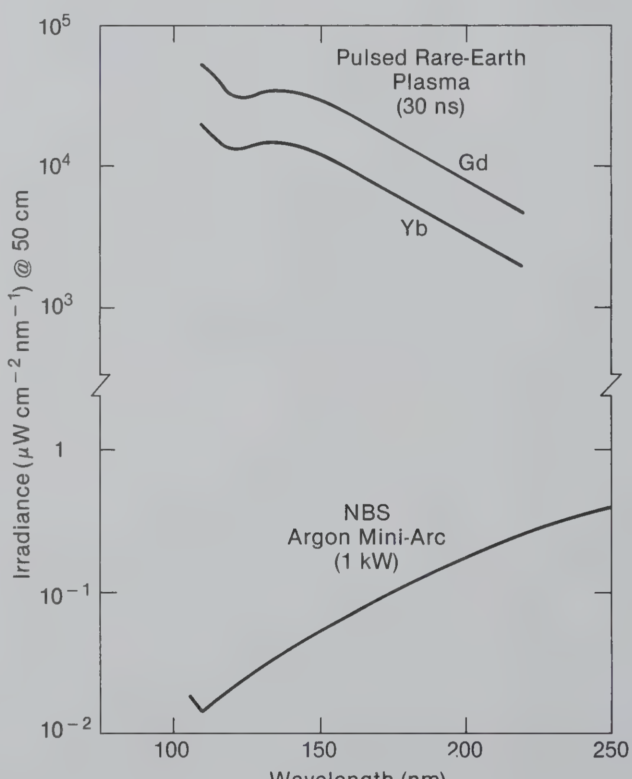


Figure 1—*Irradiance of pulsed rare-earth plasma vs. wavelength, compared with calibration source (NBS Argon mini-arc).*

NEW MASS COMPARATOR IS QUICKER, COSTS LESS

An NBS physical scientist recently designed a simple method to fabricate a 30-kg mass comparator based on a commercially-available load cell. The load cell mass comparator is used to weigh unknown masses in terms of a set of standard weights. More precise than an earlier version, the mass comparator performs with a precision of 1 part per million (ppm). Although their precisions are comparable, the load cell mass comparator is clearly an improvement over conventional balances in other ways. For similar applications, a mass laboratory might use a beam balance costing $18,000-$25,000. The balance is a fixed, permanent installation and requires about 15 minutes to make a precise mass comparison. In contrast, the load cell mass comparator can be built for about $6,000-$7,000, is readily portable, and can make a comparison in about 2 minutes.

Randall M. Schoonover, Length and Mass Measurements and Standards Division, A247 Metrology Building, 301/921-3520.

The 30-kg capacity, high precision load cell mass comparator is based on an earlier 225-kg device[1] which uses a spring force on the active load cell element nearly equal to the gravitational forces of the weights being compared even during the period when weights were exchanged. As a result, an ordinary load cell with precision of 1 part in 10,000 when used as a direct reading instrument, will perform with a precision of a few parts per million (ppm) as a mass comparator. The success of the 225 kg device indicated that scaling the method to 30 kg would be quite useful in small-mass metrology. Several members of the measurement community, however, believed that such scaling would result in serious loss of precision.

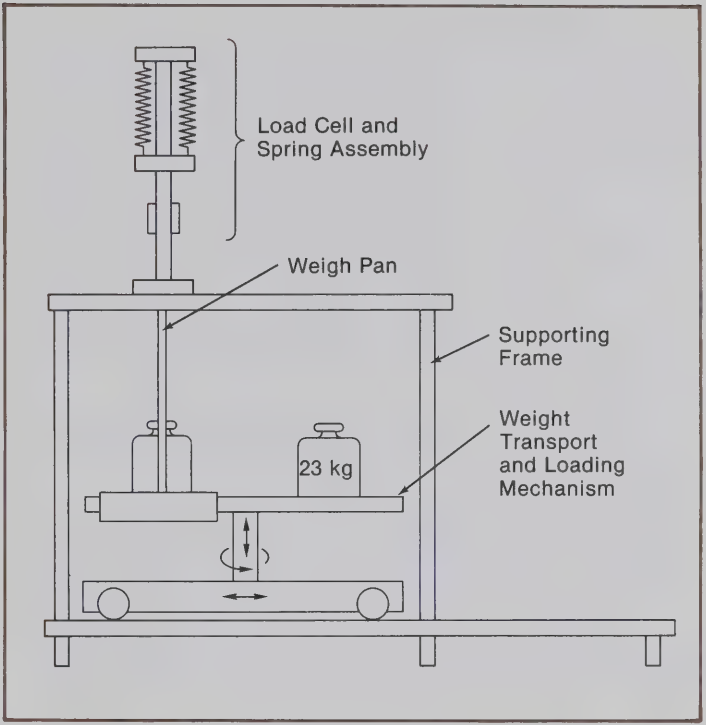


Figure 1—*Cross-sectional view showing the essential components of the constant loading mechanism.*

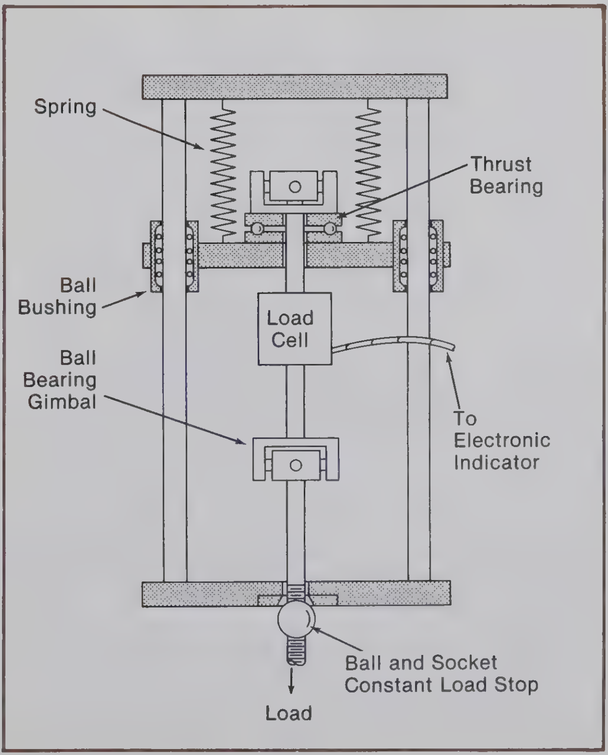


Figure 2—*A schematic view of the complete weighing system.*

---

[1] *R. M. Schoonover, "A High Precision Load Cell Mass Comparator," J. Res. NBS, Vol. 84, No. 5, Sept.-Oct. 1979, pages 347 and 351.*

Nevertheless, a 30-kg mass comparator based on the above principle was fabricated successfully and has a precision of about 1 ppm.

The 30-kg comparator differs significantly from the 225-kg version in several ways. The instrument is self-supporting and has a built-in weight exchanger as shown in figure 1. This enables the cell to be loaded without shock and also aligns the weight in the center of the weighing pan. The cell itself is supported by four parallel springs in tension rather than a single spring in compression as before. Finally, the flexure universal joints above and below the cell are replaced with gimbaled joints fabricated from ball bearing assemblies. The load cell incorporates a solid state bridge and has a capacity of 45 kg. A schematic view of the load cell and spring assembly is shown in figure 2.

Unlike the previous instrument, the springs are used to support the load cell during weighing whereas before, a mechanical shunt intervened and supported the cell. This method of supporting the cell appears to improve the isolation from ambient vibration. In addition, nearly 100 percent of the load is maintained on the cell at all times. The comparator's electronics were devised by Richard Davis, also of the Length and Mass Measurements and Standards Division, who adapted a circuit design worked out by NBS physicist Robert Cutkosky, Electrical Measurements and Standards Division.

Two different electronic load cell voltage measuring instruments were used in collecting the data. The pooled standard deviations, SD_p, for each of the two tests are given here.

A commercial bridge	Cutkosky & Davis bridge
SD_p 24 mg	30 mg

A standard deviation of 24 mg for a 30-kg comparator is about 1 ppm of the applied load. A review of commercial mechanical instruments of this capacity that contain knife edges or flexure bearings indicated that the units have a standard deviation, when used as a mass comparator, that varies between 1 and 20 mg. It is believed that if more effort is given to the load cell and associated electronic indicator design and careful attention is paid to ambient vibration isolation, this device would outperform the conventional mass comparator and operate with a precision of a few parts in 10^7 or better. This instrument would be more rugged, would reduce the measurement time, would provide much more on-scale range, and, because of its mechanical simplicity, would cost substantially less.

DATA CONVERTER CALIBRATION SERVICE ANNOUNCED

NBS scientists recently developed a new calibration service for measuring the transfer characteristics of high-performance A/D and D/A converters. The service was developed as the first step in the NBS response to the need for characterizing the uncertainties introduced by converters into measurement systems of which they are a part. This need is growing rapidly in accordance with the increasing importance of data converters in modern measurement and control instrumentation. This service will enable manufacturers and users of converters to test converters destined for highly demanding applications, satisfy traceability requirements imposed by military or government contracts, obtain independent vertification of their own test procedures through the use of transfer standards, verify the performance of converters used in automatic test equipment, or test experimental converter designs during development. Also, with the bit-error correction data provided, improved linearity performance can be realized.

Barry A. Bell, Thomas M. Souders, and Donald R. Flach, Electrosystems Division, B162 Metrology Building, 301/921-2727.

The new calibration service is based on an automated test facility developed by Souders and Flach to measure static errors for both A/D and D/A converters with systematic errors held as low as three parts per million (ppm). The facility will handle converters with a resolution of up to 18 bits. The principal parameters measured are linearity, differential linearity, offset, gain, and, for A/D converters, equivalent rms input noise.

A 20-bit D/A converter serves as a reference standard in comparisons with the unit-under-test. This reference converter incorporates a self-calibration feature so that linearity errors are held under 1 ppm. For testing D/A converters, test codewords are entered into both the reference and test converters, and their outputs are compared directly. A/D converters are compared with the reference by placing them within a feedback loop and locking the input voltage to a code-transition level defined by the input codeword to the reference converter. This input voltage is in turn compared to the output from the reference. Figure 1 shows a block diagram of this arrangement.

The transition-locking feedback loop is also used to implement an algorithm which makes possible an automatic measurement of the equivalent rms input noise of A/D converters. This measurement is important, since excess noise can often limit the effective resolution and conversion speed of A/D converters. In collaboration with James A. Lechner of the Statistical Engineering Division, the properties of Markov chains were used to determine the theoretical relationship between input noise and an expected number of counts derived digitally from the response of the feedback circuit (see inset, figure 1). As a result of this work, accurate rms noise measurements can be made concurrently with other performance tests.

Linearity measurements are made at a minimum of 1024 different codewords and the maximum, minimum, and rms values of the measured errors are determined. The data are further analyzed to determine individual bit correction coefficients and superposition errors (residual errors which cannot be eliminated by adjustments to the individual bit weights). The coefficients are calculated with Walsh transforms suitable for modeling errors in

most commonly used A/D converters and almost all D/A converters.

The technique is based on an equivalence between the logic-state sequence of individual bits during a test and the periodicity of selected Walsh functions (an ordered set of complete, orthogonal, square-like waveforms). Analogous to a Fourier series for a periodic function, a Walsh series has the property of representing a function on a finite interval, in this case, the transfer characteristics of a test converter. The coefficients obtained from the Walsh transform represent corrections to the individual bits which independently minimize the mean-squared linearity error of the test converter. These bit coefficients can be applied in a systems application (in either hardware or software implementation) to correct each codeword state of the tested converter.

Figure 2 illustrates the effect of applying bit corrections. Linearity errors of a representative precision converter are plotted against 1024 codewords uniformly distributed from minus full-scale to plus full-scale. The middle plot is of measured errors. The top plot is of errors reconstructed from 10 bit-correction coefficients by an inverse Walsh transform. The bottom plot shows the effect of applying the bit corrections from the top plot to the data of the middle plot (i.e., the bottom plot represents the differences between the middle and top plots); the remaining errors are the superposition errors.

Statistical control of the test facility is monitored through periodic tests of a state-of-the-art 18-bit converter developed for other applications by Howard K. Schoenwatter, also of the Electrosystems Division.

Data converters submitted for calibration should have resolutions from 12 to 18 bits; conversion rates of at least 10 kHz; binary coding formats including binary sign-magnitude, offset binary, 2's complement, 1's complement, or complemented versions of these; TTL compatibility; and voltage ranges of 0 to 5 V, ±5 V, 0 to 10 V, or ±10 V.

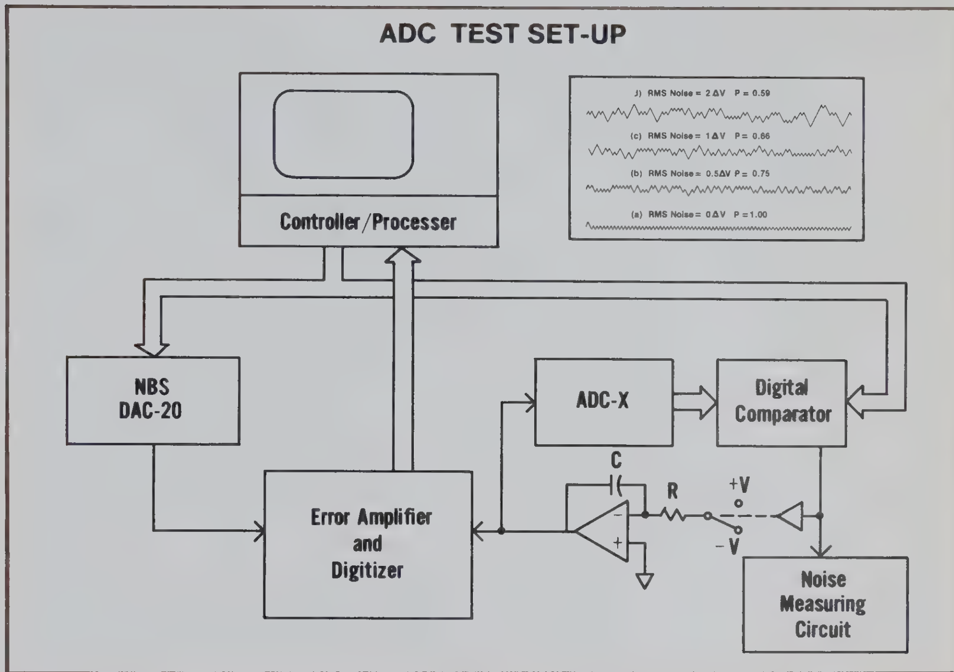
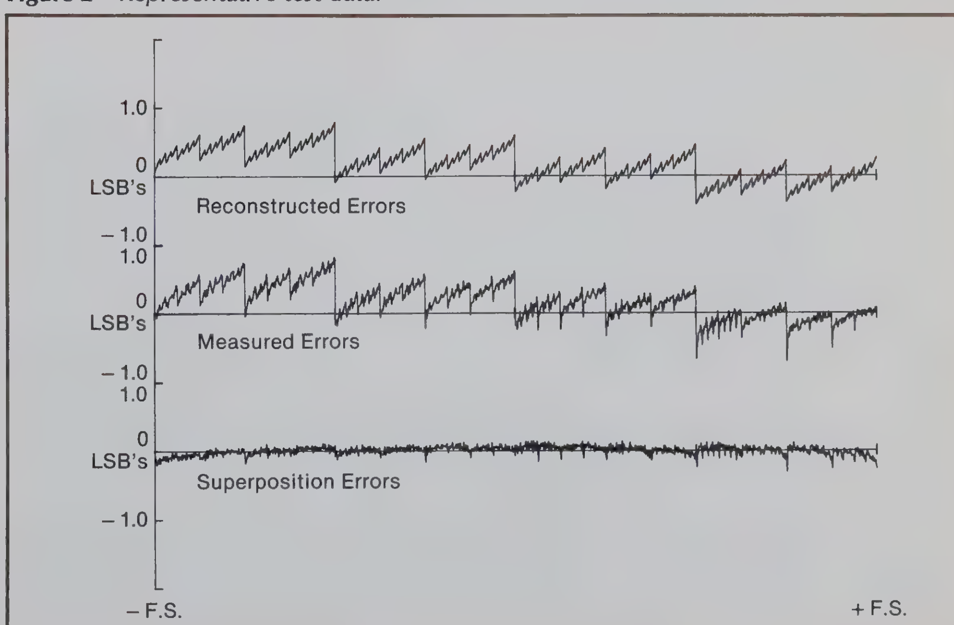


Figure 1—*Test configuration for A/D converters. Inset: Noise response of feedback loop is described by discrete valued Markov chains: converter input voltage versus time.*

Figure 2—*Representative test data.*



CONFERENCES

For general information on NBS conferences, contact JoAnn Lorden, NBS Public Information Division, Washington, DC 20234, 301/921-2721.

FIRE RESEARCH FIFTH ANNUAL CONFERENCE

The 1981 Fifth Annual Conference on Fire Research will be held at the National Bureau of Standards on August 19-21. The meeting will include overviews of important topics in fire research and provide an opportunity for the Center's grantees to meet with the Center's staff and other members of the fire research community. This year's conference will emphasize the more basic areas of fire research, including fuel pyrolysis, ignition, flame spread, steady burning, extinction, fire retardance, flame inhibition, smoke formation and properties, and fire modeling. (These topics may vary slightly when the agenda is finalized.) Anyone with an active interest in the fire research field is invited to attend.

For further information write or call: Office of Extramural Fire Research, Center for Fire Research, B250 Polymers Building, NBS, Washington, DC 20234, or Sonya Cherry, 301/921-3845.

CONFERENCE CALENDAR

August 10-14
CRYOGENICS—AN ESSENTIAL FOUNDATION FOR ADVANCED TECHNOLOGY, San Diego, CA; sponsored by NBS and Cryogenic Engineering Conference; contact: Dee Belsher, Program Information Office, Room 4001-Building 1, Boulder, CO 80303, 303/497-3981.

***August 19-21**
CONFERENCE ON FIRE RESEARCH, NBS, Gaithersburg, MD; sponsored by NBS; contact: Sonya Cherry, B250 Polymers Building, 301/921-3845.

September 14-16
SECOND INTERNATIONAL CONFERENCE ON THE DURABILITY OF BUILDING MATERIALS AND COMPONENTS, NBS, Gaithersburg, MD; sponsored by NBS, ASTM, NRC of Canada, International Council for Building Research Studies and Documentation, International Union of Testing and Research Laboratories for Materials and Structures; contact: Geoffrey Frohnsdorff, B348 Technology Building, 301/921-3485.

***September 24-25**
NATIONAL CONFERENCE ON MEDICAL DEVICES—STANDARD MEASUREMENT AND QUALITY ASSURANCE, NBS, Gaithersburg, MD; sponsored by NBS, American Medical Association, and ASTM; contact: Howard T. Yolken, A261 Metrology Building, 301/921-3768.

October 7-9
36TH CALORIMETRY CONFERENCE, NBS, Gaithersburg, MD; sponsored by NBS and University of Colorado; contact: Robert Goldberg, A303 Physics Building, 301/921-2752.

October 13-15
6TH ANNUAL CONFERENCE ON MATERIALS FOR COAL CONVERSION AND UTILIZATION, NBS, Gaithersburg, MD; sponsored by NBS, DOE, EPRI, and GRI; contact: Samuel Schneider, B308 Materials Building, 301/921-2894.

***October 21-23**
MECHANICAL FAILURES PREVENTION GROUP, NBS, Gaithersburg, MD; sponsored by NBS and MFPG; contact: Harry Burnett, B264 Materials Building, 301/921-2992.

November 23-24
DEFORMATION, FRACTURE, WEAR, AND NONDESTRUCTIVE EVALUATION OF MATERIALS: PHYSICS AND PRACTICE, New Orleans, LA; sponsored by NBS and APS; contact: Robb Thomson, A113 Materials Building, 301/921-2103.

December 8
COMPUTER NETWORKING SYMPOSIUM, NBS, Gaithersburg, MD; sponsored by NBS and IEEE; contact: Robert Toense, B226 Technology Building, 301/921-3516.

1982

January 19-21
SYMPOSIUM ON SILICON PROCESSING, San Jose, CA; sponsored by NBS and ASTM; contact: Elaine Cohen, A308 Technology Building, 301/921-3427.

***January 19-21**
COMPUTER SECURITY INITIATIVE WORKSHOP, NBS, Gaithersburg, MD; sponsored by NBS and DOD; contact: Dennis Branstad, A255 Technology Building, 301/921-3861.

***March 14-18**
6TH SYMPOSIUM ON TEMPERATURE—ITS MEASUREMENT AND CONTROL IN SCIENCE AND INDUSTRY, Washington Hilton Hotel, Washington, DC; sponsored by NBS, Instrument Society of America, and American Institute of Physics; contact: James Schooley, B130 Physics Building, 301/921-3315.

March 15-17
HUMAN FACTORS IN COMPUTER SYSTEMS, NBS, Gaithersburg, MD; sponsored by NBS and ACM; contact: Wilma Osborne, A265 Technology Building, 301/921-3485.

***March 22-26**
4TH ASTM-EURATOM SYMPOSIUM, NBS, Gaithersburg, MD; sponsored by NBS and ASTM; contact: Charles Eisenhauer, C310 Radiation Physics Building, 301/921-2658.

***March 29-April 2**
AMERICAN CRYSTALLOGRAPHERS ASSOCIATION, NBS, Gaithersburg, MD; sponsored by NBS and Crystallographers Association; contact: Camden Hubbard, A221 Materials Building, 301/921-2921.

***April 13-15**
MECHANICAL FAILURES PREVENTION GROUP, NBS, Gaithersburg, MD; sponsored by NBS and MFPG; contact: Harry Burnett, B264 Materials Building, 301/921-2992.

**New Listings*

PUBLICATIONS

SOLAR COMPONENTS ON LOW SLOPED ROOFS

*Mathey, R. G., and Rossiter, W. J., Jr., Guidelines for the Installation of Solar Components on Low-Sloped Roofs, Nat. Bur. Stand. (U.S.), Tech. Note 1134, 81 pages (Nov. 1980) Stock No. 003-003-02261-6, $4 prepaid.**

The National Bureau of Standards has issued an 81-page report giving guidelines for the retrofit installation of solar collectors and related equipment on low-sloped roofs of commercial and industrial buildings.

The guidelines, focusing mainly on the waterproofing integrity of the roofing system, access to the collectors and roofing attachment of different types of collector support frames, and safety, are the result of research conducted by the NBS Center for Building Technology. The research was sponsored by the U.S. Department of Energy.

Until now, no guidelines were available to help in the installation of solar components on existing low-sloped roofs. The design of solar systems for such roofs generally has not taken into account how the solar components and the roofs interact.

The guidelines are intended to promote adequate performance of roofing systems having retrofitted solar equipment. But many of the recommendations can apply to new roofing systems as well. With proper design, construction, and maintenance, low-sloped roofs can resist water penetration for 20 years or more. The installation of solar equipment should not adversely affect their lifespan. Improper installation, however, may shorten a roofing system's service life, causing leaks and premature failure.

The guidelines also deal with several factors in the performance of the solar collectors, such as attachment to the roof and wind uplift, and suggest ways to evaluate the condition of existing roofing.

NBS researchers developed the guidelines after gathering technical information from the literature, building codes, roofing field surveys, and acceptable roofing practices.

** Publications cited here may be purchased at the listed price from the U.S. Government Printing Office, Washington, DC 20402 (foreign: add 25 percent). Microfiche copies are available from the National Technical Information Service, Springfield, VA 22161. For more complete periodic listings of all scientific papers and articles produced by NBS staff, write: Editor, Publications Newsletter, Administration Building, National Bureau of Standards, Washington, DC 20234.*

NBS ISSUES REHABILITATION GUIDES

Chapman, R. E., Cost Estimation and Cost Variability in Residential Rehabilitation, Nat. Bur. Stand. (U.S.), Bldg. Sci. Ser. 129, 120 pages (Nov. 1980) Stock No. 003-003-02270-5, $4.50.

Steep prices for new homes have forced many prospective owners to consider renovating older houses. Renovation, however, entails certain costs and risks which should be clearly understood through accurate cost estimation and reliable condition assessment.

Now participants in building rehabilitation—private investors, financial institutions, engineers, architects, contractors, and government officials—can benefit from the results of new research from the National Bureau of Standards. Details are described in two NBS reports.

Cost Estimation and Cost Variability in Residential Rehabilitation (BSS 129) describes and critiques four conventional methods for estimating housing renovation costs. Prepared by the Bureau's Center for Building Technology (CBT), the report focuses on how these methods incorporate renovation's inherent riskiness into the housing investment decision. The study concludes that the "cost function" method is the most consistent for estimating residential rehabilitation costs. Special features include a list of recommendations for future research; an econometric analysis of actual housing renovation projects; and a technical appendix showing how a cost function can be derived.

Selected Methods for Condition Assessment of Structural, HVAC, Plumbing, and Electrical Systems in Existing Buildings (NBSIR 80-2171) also was prepared by CBT, with the support of the U.S. Department of Housing and Urban Development. According to its authors, rehabilitating an existing building can present unique construction problems because most of the building's systems may be affected. Assessment of these systems varies from simple visual inspection to laboratory testing, which may require sophisticated equipment and trained personnel. The report emphasizes the more technically complex evaluation techniques for a broad range of systems. It is designed to help a building owner, designer, builder, or regulatory official make educated judgments about the type and degree of changes needed in a building being rehabilitated. The authors describe commonly used field methods and possible laboratory methods, and provide comparative tables to help in choosing the most appropriate evaluation methods for each parameter being tested.

Copies of the 100-page *Selected Methods for Condition Assessment of Structural, HVAC, Plumbing, and Electrical Systems in Existing Buildings* are available free from James H. Pielert, B226 Building Research, NBS, Washington, DC 20234, or phone 301/921-3146.

STUDY OF ROCK SALT PROPERTIES

Gevantman, L. H., Physical Properties Data for Rock Salt, Nat. Bur. Stand. (U.S.), Monogr. 167, 288 pages (Jan. 1981) Stock No. 003-003-02166-1, $12 prepaid.

To answer the nuclear waste management community's urgent need for a single, easily identified source of data on rock salt's physical properties, a comprehensive book on this subject has been published by the National Bureau of Standards.

Physical Properties Data for Rock Salt (Monograph 167) is a compendium covering a wide range of characteristics—geological, mechanical, optical, thermal, radiation damage, electrical, magnetic, chemical, and physical.

Solving the question of what to do with nuclear debris, which can remain dangerously radioactive for 10,000 years, is one of the United States' most pressing energy problems. Scientific research indicates that rock salt deposits may be a suitable, stable repository for radioactive nuclear wastes.

Until now, according to the report, data on rock salt properties have not been presented "in a form that permits designers of waste burial facilities to extract the variety of numerical values for use with any degree of confidence."

As a result, the NBS Office of Standard Reference Data was asked by the Department of Energy and the Office of Nuclear Waste Isolation to undertake a data evaluation project for rock salt properties. NBS was assisted by three data centers: the Center for Information and Numerical Data Analysis and Synthesis, Purdue University; the Molten Salts Data Center, Rensselaer Polytechnic Institute; and the National Center for Thermodynamic Data of Minerals, U.S. Geological Survey.

While the report was assembled primarily to satisfy nuclear waste storage needs, data for most of the properties cited may also apply to the burial of other types of debris where long-term, stable facilities are required.

The report's six chapters present the best available data on their respective properties in both tabular and graphic form. Wherever possible, recommended values and error limits are given. The analysis of each property is enhanced by a brief discussion of measurement techniques used.

SCIENCE, ENGINEERING ADVANCES AT NBS HIGHLIGHTED

Porter, G., National Bureau of Standards 1980, Nat. Bur. Stand. (U.S.), Spec. Publ. 600, 40 pages (Jan. 1981) Stock No. 003-003-02300-1, $2.50 prepaid.

A new report reviews recent science and engineering research advances at NBS.

National Bureau of Standards 1980 explains the bureau's role as the central U.S. reference laboratory for the physical and engineering sciences. It also discusses briefly bureau plans for its programs in electronics, automation, chemical processing, and materials research.

Included in the 40-page report are highlights of recent accomplishments within the bureau's National Measurement Laboratory, National Engineering Laboratory, and Institute for Computer Sciences and Technology. More than 40 different projects are described. They cover areas such as basic measurements and standards, energy research, environmental measurements, materials properties, industrial productivity, fire safety, building technology, calibration methods, and computer standards and guidelines.

Also featured are summaries of NBS services to industry, other government agencies, and the public, as well as information on cooperative research programs and a directory of the names, titles, and phone numbers of NBS research managers.

PUBLICATIONS LISTING

Computer Science and Technology

Federal Computer Performance Evaluation and Simulation Center, Computer Science and Technology: Computer Model Documentation Guide, Nat. Bur. Stand. (U.S.), Spec. Publ. 500-73, 56 pages (Jan. 1981) Stock No. 003-003-02289-5, $4.75 prepaid.

Adrion, W. R., Branstad, M. A., and Cherniavsky, J. C., Computer Science and Technology: Validation, Verification, and Testing of Computer Software, Nat. Bur. Stand. (U.S.), Spec. Publ. 500-75, 62 pages (Feb. 1981) Stock No. 003-003-02289-6, $3.75 prepaid.

Houghton, R. C., Jr., Computer Science and Technology: Features of Software Development Tools, Nat. Bur. Stand. (U.S.), Spec. Publ. 500-74, 24 pages (Feb. 1981) Stock No. 003-003-02295-1, $1.75 prepaid.

Energy Conservation and Production

Elder, J., and Tibbot, R. L., User Acceptance of an Energy Efficient Office Building. A study of the Norris Cotton Federal Office Building, Nat. Bur. Stand. (U.S.), Bldg. Sci. Ser. 130, 122 pages (Jan. 1981) Stock No. 003-003-02278-1, $4.50 prepaid.

McCarty, R. D., Four Mathematical Models for the Prediction of LNG Densities, Nat. Bur. Stand. (U.S.), Tech. Note 1030, 84 pages (Dec. 1980) Stock No. 003-003-02285-3, $4 prepaid.

Waksman, D., Streed, E., and Seiler, J., NBS Solar Collector Durability/Reliability Test Program Plan, Nat. Bur. Stand. (U.S.), Tech. Note 1136, 85 pages (Jan. 1981) Stock No. 003-003-02283-7, $4 prepaid.

Failure Analysis

Free, G. M., Eddy Current Nondestructive Testing, Proceedings of the Workshop on Eddy Current Nondestructive Testing, held at the National Bureau of Standards, November 3-4, 1977, Gaithersburg, MD, Nat. Bur. Stand. (U.S.), Spec. Publ. 589, 153 pages (Jan. 1981) Stock No. 003-003-02287-0, $5.50 prepaid.

Lasers and Their Applications

Young, M., The Use of LED's to Simuluate Weak YAG-Laser Beams, Nat. Bur. Stand. (U.S.), Tech. Note 1031, 48 pages (Jan. 1981) Stock No. 003-003-02290-2, $2.50 prepaid.

Measurement Science and Technology: Physical Standards and Fundamental Constants

Kieffer, L. J., Ed., Calibration and Related Measurement Services of the National Bureau of Standards, Nat. Bur. Stand. (U.S.), Spec. Publ. 250, 105 pages, 1980 Edition (Mar. 1981) Stock No. 003-003-02299-3, $4.50 prepaid.

Nuclear Physics and Radiation Technology

Eisenhower, E. H., Chairman, ANSI Subcommittee N43-3.5, American National Standard N432; Radiological Safety for the Design and Construction of Apparatus for Gamma Radiography. (ANSI N432-1980), Nat. Bur. Stand. (U.S.), Handb. 136, 19 pages (Jan. 1981) Stock No 003-003-02293-4, $1.50 prepaid.

NEWS BRIEFS

SUPER SENSITIVE SQUID. A low-noise, direct current SQUID (superconducting quantum interference device) developed by NBS approaches the theoretical limit of sensitivity in measuring magnetic fields. The ultra-sensitive superconducting integrated circuit device is a research tool used to determine the operational limits of detection. A sensor of similar design is being developed to measure external fields for applications in basic physics, biomagnetism, and gravimetry.

STUDY OF FRACTURE COSTS IN U.S. UNDERWAY. The NBS Fracture and Deformation Division and Battelle Columbus Laboratories are conducting a 19-month study of the economic aspects of fracture in the United States. The study was requested by the U.S. House of Representatives Committee on Science and Technology. Using input-output economic methods, the researchers will determine the national costs of unintended fracture and fracture prevention, and will estimate the reductions in cost that could be made by employing the best available materials and methods and by doing more fracture-related research. All kinds of materials (metals, ceramics, polymers, composites, etc.) in all sectors of the economy will be examined. A progress report on the application of the input-output methodology to selected sectors is available.

NEW DEVICE HELPS ARMY IN MEASURING ELECTROMAGNETIC RADIATION. NBS researchers have developed an automated, highly portable system that Army personnel can use for determining electromagnetic radiation levels and for tracing interference problems. Consisting of five antennas, three commercial receivers, and a microprocessor that controls the operation, the system has a frequency range from 10 KHz through 18 GHz. Using the new NBS system, the Army can realize a personnel saving of 3-to-1 and on-site measurement time can be reduced by a factor of 10.

GUIDELINES TO HELP IN IDENTIFICATION OF ARSON ACCELERANTS. NBS is developing draft guidelines to help forensic laboratory chemists identify arson accelerants from fire debris. Gasoline, kerosene, and paint thinner are among the most common accelerants used by arsonists. In a cooperative effort with the Treasury Department's Bureau of Alcohol, Tobacco and Firearms (ATF), the NBS Center for Fire Research is working with an advisory panel of forensic laboratory directors to prepare the consensus guidelines for analyzing accelerants. Eventually, the guidelines could be adopted by voluntary standards organizations. To assess the effectiveness of this proposed approach, NBS and ATF will coordinate an interlaboratory evaluation.

STANDARDS FOR SUPERCONDUCTORS. NBS, manufacturers, and users are jointly developing voluntary standards for superconducting wires. The standards--involving both software and hardware--will reduce costs and increase reliability of superconductors in a growing market that includes fusion and other advanced energy systems. The software standards will comprise procedural techniques for measurements and standard nomenclature for accurate communication of superconductor properties. Hardware standards will be concerned principally with the production of standard reference materials accurately characterized as to critical temperature, current, and magnetic field.

NEXT MONTH IN

DIMENSIONS/NBS

The Bureau's Research Associate Program enables scientists and engineers from private companies, trade and professional associations, and other organizations to conduct cooperative research at NBS on projects of mutual interest. Read about the program in the next issue of DIMENSIONS/NBS.

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

NATIONAL BUREAU OF STANDARDS
Ernest Ambler, Director

Prepared by the Public Information Division
Washington, DC 20234

Richard S. Franzen, Chief

Sharon Shaffer, Chief
General Publications

Jan Kosko, Acting Editor

Justine A. Williams, Assistant Editor

Stan Lichtenstein, Production

Walt Mortensen, Visual Editor
(Commerce Department)

PHOTO CREDITS

Beamie Young, pages 2 and 5.

Photo on page 11 courtesy of HUD.

Mark Helfer, pages 14, 16 and 17.

The Commerce Department's National Bureau of Standards was established by Congress in 1901 to advance the Nation's science and technology and to promote their application for public benefit. NBS research projects and technical services are carried out by the National Measurement Laboratory, the National Engineering Laboratory, and the Institute for Computer Sciences and Technology. Manufacturing, commerce, science, government, and education are principal beneficiaries of NBS work in the fields of scientific research, test method developments, and standards writing. DIMENSIONS/NBS describes the work of NBS and related issues and activities in areas of national concern such as energy conservation, fire safety, computer applications, materials utilization, and consumer product safety and performance. The views expressed by authors do not necessarily reflect policy of the National Bureau of Standards or the Department of Commerce.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Annual subscription: Domestic, $11.00, foreign, $13.75. Single copy: Domestic, $1.10, foreign, $1.40. The Secretary of Commerce has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through June 30, 1981.